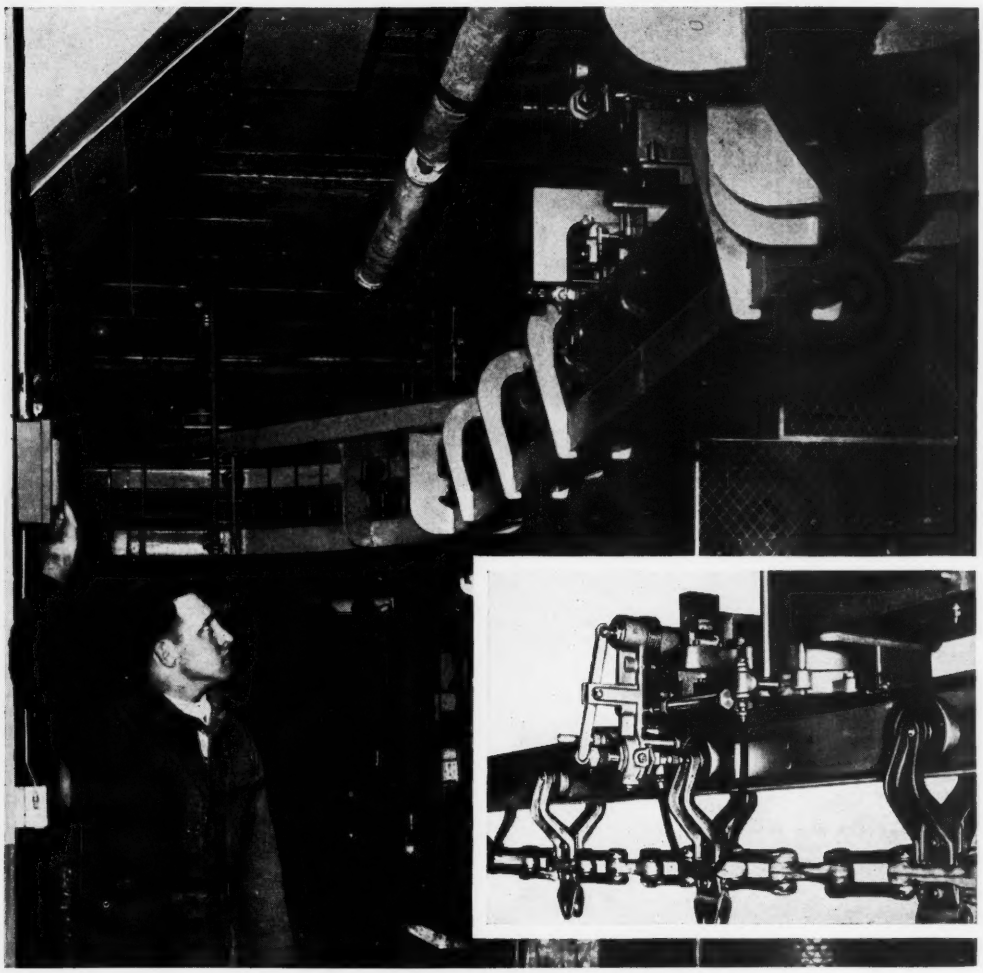
Vol. 12, No. 4 July-August, 1956

LUBRICATION ENGINEERING

RESEARCH APPLICATION EDUCATION MAINTENANCE



Lubricating Conveyor Trolley Wheels
(Cover Story, p. 277)

JOURNAL OF THE AMERICAN SOCIETY OF LUBRICATION ENGINEERS

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LUBRICATION ENGINEERING

RESEARCH · APPLICATION · EDUCATION · MAINTENANCE

Volume 12, No. 4 July-August, 1956

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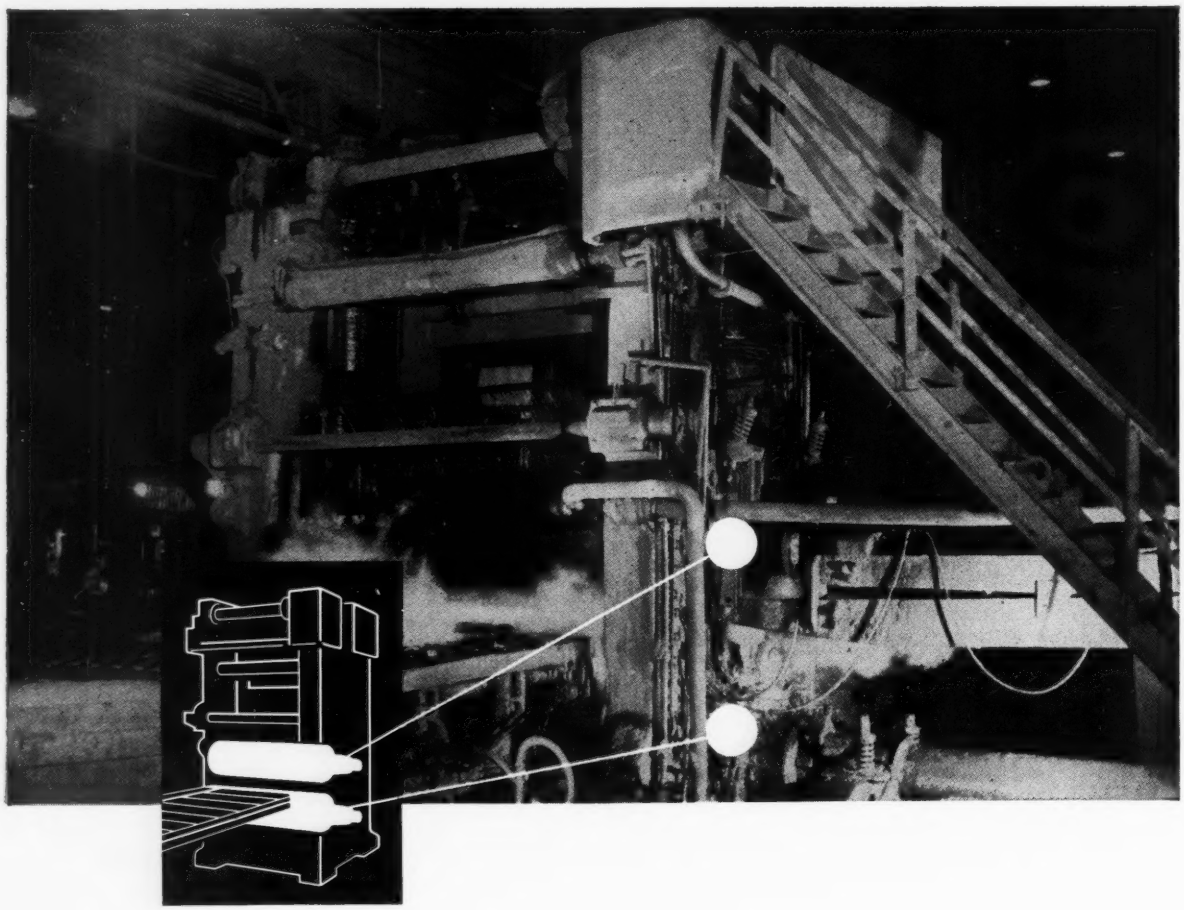
Lubricating roll necks is no easy job



Lubricating the roll necks of a steel mill calls for a lubricant that will resist high temperatures. The lubricant must also function in the presence of steam, water, mill scale and other abrasive materials. It has to cushion great shock loads and cling tenaciously to the bearings it protects. It must last a long time... and it must be economical in use.

Atlantic Lubricant 10 performs exceptionally well in this service. It is being used in a pressure system on the mill illustrated, at the Lukens Steel Company in Coatesville, Pa., for the lubrication of roll neck bearings, pinion and spindle bearings.

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Lubrication in the News

Preventive Maintenance Program. A general industry shortage of skilled hydraulic maintenance specialists to service increasingly complex automation machinery is being solved by Packard-Clipper Div., Studebaker-Packard Corp., with a division-wide, 40-week planned preventive maintenance program at the company's engine and transmission plant in Utica, Michigan. Divided into 12 separate categories, the two-hour weekly training sessions consist of films, lectures, demonstrations, and practical shop work, closely followed up by problems encountered in actual experience during the work week.

Pictured above are members of the company's hydraulic maintenance program being instructed by Marshall Swisher (center), Supervisor of Hydraulics, during part of their on-the-job training session.

ASLE-ASME Lubrication Conference. Preliminary plans for the third jointly-sponsored Lubrication Conference indicate that special attention will be given to problems involved in the lubrication of nuclear power equipment. Eight research papers in this rapidly developing field range from studies of fluid metal as lubricants to the effect of radiation on petroleum products.

Another highlight of the Conference will be a "reporter type" session devoted to papers on hydrodynamic lubrication. This type of meeting assumes that the papers will have been read and studied prior to their presentation and, consequently, only a synopsis of each paper will be given by a reporter. It is expected that most of the session will be devoted to discussions and authors' closures.

Other subjects that will be covered include boundary lubrication and lubricants. Approximately 22 research and development papers will be presented during the conference period.

As in previous conferences, there will be no conflicting sessions, and those attending will have the opportunity to hear the presentation of all papers. The practice of providing registrants with preprints of the papers to be presented will be continued.

The Conference will be held October 8, 9, and 10, at the Chalfonte-Haddon Hall, Atlantic City, N. J.

"Hot Boxes" on freight car journal bearings, caused by excessive friction build-up, can now be eliminated. A new patent, No. 2,736,620, recently issued to Commonwealth Engineering Co. of Ohio, describes a new and novel method of positive pressure lubrication. This contrasts with the present method consisting of a lubricated pad arrangement known as "waste lubrication." Prime objective of the new invention is to give a large, continuous flow of lubricant to the journal bearings. Besides this, it will assist in heat dissipation from the bearing surface which will reduce the running temperature of the bearing. The system also filters the lubricant before it reaches the bearing.

Key to the new method is a bearing shoe with apertures. The apertures let the lubricant flow to the rotating shaft. A pump is operated from the shaft; when the shaft rotates, lubricant flows from its supply source within the overall structure through the perforated bearing shoe to the shaft. As a safety measure, the overall housing may also contain a pad arrangement that is constantly supplied with lubricant.

Further information can be obtained by writing Commonwealth at 1771 Springfield St., Dayton 3, Ohio. The company will not manufacture the new invention, but will license its use.

New American Standards (approved in 1955) in the field of lubrication include:

Z11.84-1955 (ASTM D1298-54), Method of test for specific gravity of petroleum and its products (hydrometer method).

Z11.85-1955 (ASTM D665-54), Test for rust-preventing characteristics of steam-turbine oil in the presence of water.

Z11.86-1955 (ASTM D936-55), Test for aromatic hydrocarbons in olefin-free gasolines by silica gel adsorption.

Z11.87-1955 (ASTM D943-54), Test for oxidation characteristics of inhibited steam-turbine oils.

Z11.88-1955 (ASTM D1015-55), Test for measurement of freezing points of high-purity compounds for evaluation of purity.

Z11.89-1955 (ASTM D1016-55), Test for determination of purity from freezing points.

Z11.90-1955 (ASTM D1021-55), Test for oxygen in butadiene vapors (manganous hydroxide method).

Z11.91-1955 (ASTM D1265-55), Test for sampling liquefied petroleum gases.

Z11.92-1955 (ASTM D1267-55), Test for vapor pressure of liquefied petroleum gases.

Additional information or a review copy of a standard listed above, may be obtained by writing Public Relations, American Standards Assoc., 70 E. 45th St., New York 17, N. Y.

National Conference on Industrial Hydraulics. Hydraulic applica-

(Continued on p. 279)

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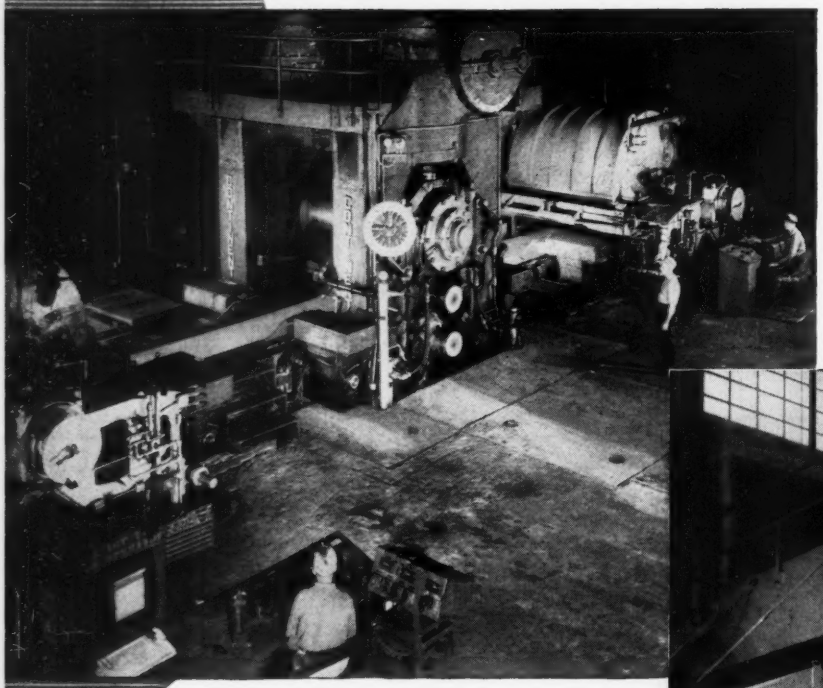

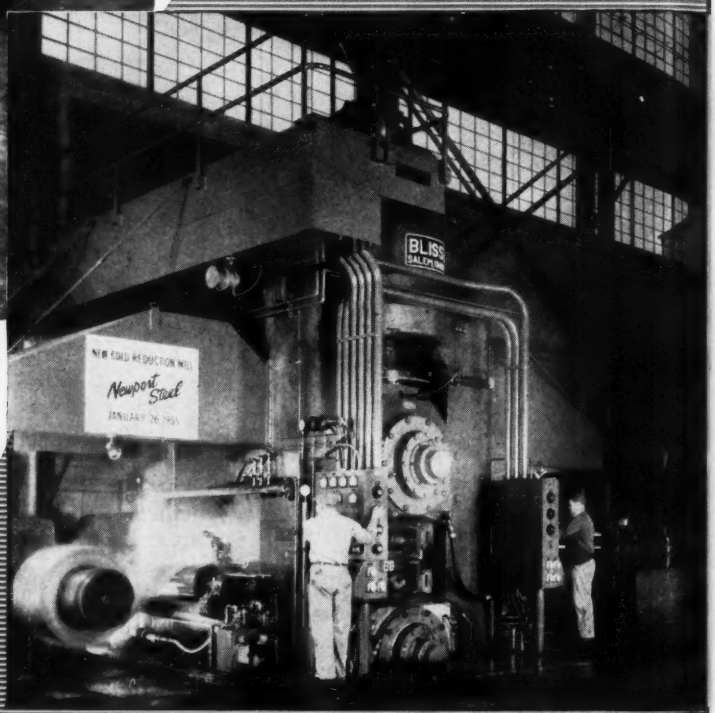

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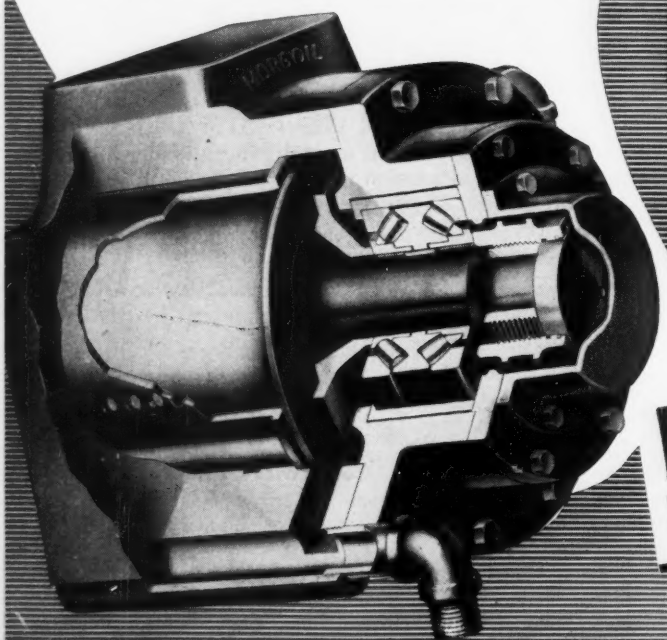

The recent modernization at NEWPORT STEEL CORPORATION, Newport, Kentucky, features a four-high reversing hot mill with Steckel-type furnaces and a four-high cold reduction mill. BOTH mills are equipped with MORGOIL bearings for maximum efficiency.

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Section News

BOSTON, November '55 meeting. L. O. Witzenburg, Sales Manager for The Farval Corp., spoke on the history and development of centralized lubrication, assisted by T. J. Gruber, Farval's Service & Research Manager; followed by B. M. Dunham, Technical Consultant, Industrial Products Dept., of the Sun Oil Co., who discussed the latest developments in petroleum lubricants for use in centralized lubrication.

January. "Lubrication Problems in Fabrication of Metals Involved in the Nuclear Power Field," by P. Lowenstein, Nuclear Metals, Inc.; followed by a panel discussion on "Metal Forming Lubricants," with Dr. B. G. Rightmire, Massachusetts Institute of Technology, as Moderator, and R. Ryder (General Electric Co.), M. Petronio (Frankford Arsenal), and E. Erickson (Pennsylvania Salt Mfg. Co.) as Panelists.

March. "Manufacture of Lubricating Oils," by R. W. VanSant, Jr., Gulf Oil Corp., showing the particular effect of the refining process on the finished oils, and the results of these properties on their performance characteristics.

April. Plant Tour of the Brown & Sharpe Manufacturing Co., Providence, R. I., followed by a paper entitled "Machine Tool Maintenance," by F. E. Manchester, Brown & Sharpe's Superintendent of Central Services Div., stressing particularly the preventive maintenance aspect.

May. Past Chairman's Night, preceded by Election of Officers (see ASLE Directory); followed with a lecture and demonstration on the art of glass blowing by R. L. Phipps. (Submitted by G. T. Collatz, Sec'y.)

BUFFALO, May meeting. J. R. Stitt, Manager, Oil Additive Div., of Oronite Chemical Co., presented a paper entitled "Development & Use of Additives in Modern Industrial & Automotive Oils."

June. Annual Outing, held at the Buffalo Launch Club. (Submitted by L. E. Locke, Jr., Sec'y.)

CHICAGO, April meeting. P. A. Bennett, Research Engineer, General Motors Corp., presented a paper entitled "Passenger Car Lubrication."

May. "Fire-Resistant Hydraulic Fluids," by Dr. W. H. Millett, Special Products Dept., Carbon & Carbide Chemicals Co.; preceded by Election of Officers (see ASLE Directory). The newly-elected Executive Committee includes: R. D. Clevenger (D. A. Stuart Oil Co.), A. B. Two (Ford Motor Co.), I. P. Perkins (Penola Oil Co.), and A. B. Wilder (E. I. du Pont de Nemours & Co., Inc.).

June. Annual Golf Party. (Submitted by J. N. Waddell, Vice-Chrmn.)

KINGSPORT, March meeting. Two motion pictures entitled "Oil Films in Action" and "Petroleum" were shown, preceded by Election of Officers (see ASLE Directory). Newly-elected Directors include: W. T. Williams (Tennessee Eastman Co.), C. L. Peterson (The Mead Corp., Kingsport Div.), and G. Blakely (Holliston Mills). (Submitted by H. Woods, former Sec'y-Treas.)

LOS ANGELES, April meeting. C. E. Francis, Shell Oil Co., presented a paper entitled "The Place for Emulsions as Fire-Resistant Power Transmission Fluids."

May. "The How & Why of Ball Bearing Lubrication," by Dr. D. F. Wilcock, General Electric Co.; preceded by Election of Officers (see ASLE Directory). Newly-elected Executive Committee members include: M. K. Carter (Union Oil Co.), J. B. Malin (E. I. du Pont de Nemours & Co., Inc.), and W. R. Mayhew (Mayhew Products Co.).

June. First Annual Ladies' Night, which included a plant tour of the Schlitz Brewery, Van Nuys, Calif., followed by a discussion on "The Brewer's Brewing Problems," by J. L. Pahlow, Plant Manager. (Submitted by R. F. Connelly, Sec'y-Treas.)

LOUISVILLE, May meeting. Election of Officers (see ASLE Directory). (Submitted by J. K. Wyatt, Sec'y-Treas.)

MILWAUKEE, April meeting. A. L. Hartley, Chief Metallurgist, The Cincinnati Milling Machine Co., presented a paper entitled "Advantages of a Planned Lubrication Program," showing how a well-planned lubrication program can decrease by at least 30% the maintenance hours required to keep machine tools operating.

May. Annual Ladies' Night, featuring W. J. Meinhardt, President of the Meinhardt Diamond Tool Co., whose topic embraced "Industrial, Synthetic and Jewel Diamonds." (Submitted by J. H. Berg, Sec'y.) (Continued on p. 279)

H. Apkarian (General Electric Co.), Chairman of the recently-formed ASLE "Mohawk-Hudson" Section. Other Officers include: R. McBride and D. F. Wilcock (General Electric Co.), Vice-Chairman and Program Chairman, respectively; E. S. Preble (Shell Oil Co.), Secretary-Treasurer; and W. Fiedler, Jr. (Schenectady General Army Depot), Membership Chairman.

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Lube Lines

by A. F. Brewer*

LUBRICATION FAILURE. Management should realize that lubricants as well as machinery can fail in service. From the viewpoint of lubricants, this term "lubrication failure" requires explanation. In effect it involves disintegration by disruption of the molecular structure, or deterioration according to the type of lubricant. Pressures and temperatures in excess of the range for which a lubricant has been designed are the primary cause. The resultant inability of a lubricant to perform its intended function under these conditions is in reality a "lubrication failure" due to impairment or deterioration of its lubricating ability. It may or may not involve chemical decomposition unless complex additives are present. For this reason the word "breakdown" does not apply as specifically to lubricants as to machinery. Usually when lubricating ability is reduced, a machine failure will be impending before the lubricant has completely lost its protective ability. The conditions — very high temperature or excessive loading on a bearing, gear, or chain — probably have been promoting change in steel structure at the same time the body or film strength of the lubricant has been sufficiently reduced to result in "boundary" or inadequate lubrication.

Lubrication failures vary according to the service and type of machine. In a circulating oiling system in steel mill service, high temperature and water contamination are the primary causes. In an internal combustion engine, fuel dilution of the crankcase oil can reduce the viscosity to such an extent as to promote bearing failure, especially under high speed, high-temperature operation. A ball or roller bearing can be ruined by lubrication failure if the seals are impaired by overzealous use of a grease gun, and contamination of the grease in the bearing results from abrasive dirt, water, or acids being drawn in by windage past the seals. This can be particularly apt to occur in motor service.

The changes which are taking place continually in machine design and operation must be regarded as related to lubrication failure, although the petroleum industry and the chemists are keeping well up with these changes. Research in the fields of additives and non-petroleum lubricants is more intensive than ever. It must be, to prepare lubricants capable of functioning at speeds up to 100,000 rpm., at temperatures ranging from —100°F. to around 500°F. or even higher. Throughout, the possibility of oxidation is ever-present. The oxidation process increases rapidly as temperatures are increased. It is accelerated by certain metals such as copper, and by sludge formation where water has leaked into the

(Continued on p. 285)

*Consultant, and Author of "Basic Lubrication Practice."

PREPRINT ORDER BLANK

A limited supply of the following preprints of papers presented at the ASLE 11th Annual Meeting, Pittsburgh, April 4-5-6, 1956, are currently available at 35c each to members, 50c each to non-members. Indicate number of copies desired, fill in your name and address, enclose remittance, and mail to:

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_____(AM4C-3) **Appraisal of Rolling Oil Testing, An,** by S. A. Paradee
_____(AM1B-1) **Assessment of Automobile Bearing Performance from Field Tests, The,** by W. E. Duckworth & P. G. Forrester
_____(AM3A-2) **Capillary Viscometry of Lubricating Grease,** by L. C. Brunstrum & R. H. Leet
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_____(AM2B-2) **Dynamic Demulsibility Characteristics of Oils,** by E. W. Brennan & R. G. Moyer
_____(AM3B-2) **Effect of Engine Operation on Synthetic Gas Turbine Lubricants,** by J. H. Way & T. F. Davidson
_____(AM6A-2) **Electron Diffraction in Lubrication Research,** by D. Godfrey
_____(AM1B-2) **Evaluation of Anti-Scuff Properties of Oils,** by D. M. Teague, E. H. Loeser, P. J. Willson & S. B. Twiss
_____(AM1B-3) **Evaluation of Anti-Wear Properties of Oils,** by S. B. Twiss, E. H. Loeser & D. M. Teague
_____(AM3C-2) **Experimental Investigation of Railroad Journal Bearing Operating Characteristics,** by G. L. Pigman & A. L. Busby
_____(AM3A-1) **Grease Flow in Shielded Bearings,** by R. O'Halloran, J. J. Kolfenbach & H. L. Leland
_____(AM3C-3) **Investigation of Oil Additives for Boundary Lubrication of Railroad Journal Bearings,** by A. Miller & A. A. Anderson
_____(AM2C-1) **Lubrication Engineer Surveys Steel Mill Gearing, A,** by A. E. Cichelli
_____(AM2C-3) **Lubrication in the Presence of Nuclear Radiation,** by R. O. Bolt & J. G. Carroll
_____(AM5A-1) **Lubrication of Aircraft Oscillating Control Bearings at High Temperatures,** by D. C. McGahey & R. S. Barnett
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_____(AM4B-3) **Place of Emulsions as Fire-Resistant Power Transmission Fluids, The,** by G. T. Coker, Jr. & C. E. Francis
_____(AM2A-3) **Problems in Hydrodynamic Lubrication,** by E. K. Catcombe
_____(AM1A-2) **Spray Application of Lubricants to Plain Roll Neck Bearings,** by J. S. Aarons & C. M. Winn
_____(AM5A-3) **Study of Combustion-Resistant Hydraulic Fluids as Ball Bearing Lubricants, A,** by H. V. Cordiano, E. P. Cochran, Jr. & R. J. Wolfe
_____(AM2A-1) **Surface Viscosity & Elasticity of Lubricating Oils,** by D. W. Criddle
_____(AM2B-3) **Synthetic Ester Lubricants with Improved Lubricity & Thermal Stability,** by M. Z. Fainman & R. S. Barnes
_____(AM6C-1) **Where We Stand on Fire-Resistant Turbine Fluids: A Progress Report,** by J. J. O'Connor

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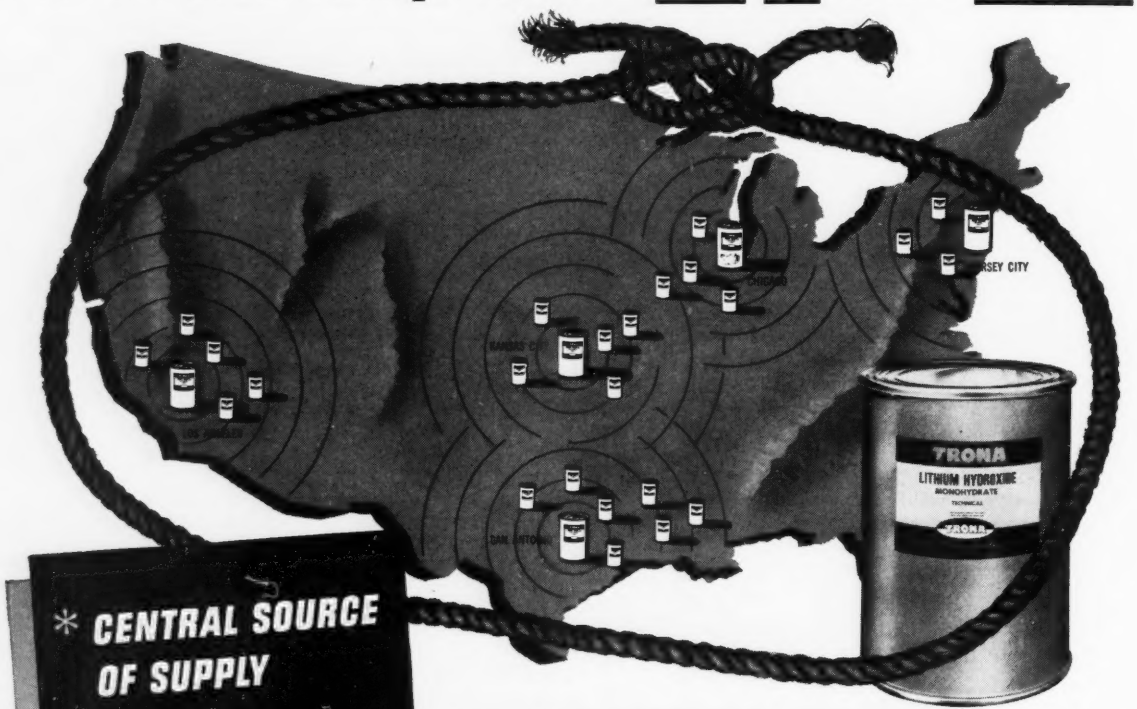

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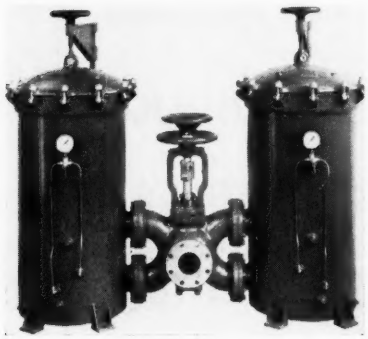
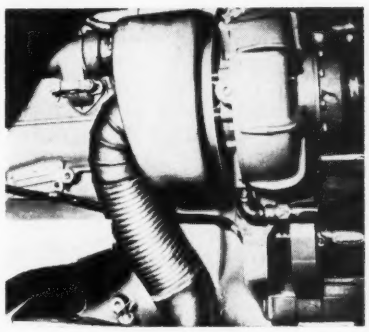


Duplex Lube Oil Filter. A new large-capacity duplex full-flow lube oil filter is now available, consisting of two parallel filters with a flanged switching valve supported between them (see picture above). Each filter has a capacity of 225 GPM of 150 SSU viscosity lubricating oil at about 5 psi pressure drop, and may be operated independently or in parallel; each is equipped with a 3-way cock and differential pressure gauge. A cover-lifting mechanism facilitates cover removal and exchange of filter recharges. The filter cartridge is a laminated, crenulated fiber disc type affording action both through proximate discs and adjacent portions to provide maximum filtering capacity. It is an "extended area" filter (actual filtering area is greater than the area of its container), having high flow rate at low-pressure drop combined with the extremely fine filtering absorption and neutralizing properties of a depth-type filter. The filter recharge is expendable and is claimed to have a useful life of from 4 to 10 times that of other types. (Wm. W. Nugent & Co., LE-12/4, 3440 Cleveland St., Skokie, Ill.)

Solenoid Valve. The "In-Line" construction of the Airmatic 2-way direct solenoid-controlled valve makes it easy to inspect and service. All control parts can be removed in one small assembly without disturbing the piping by loosening just one hexagonal nut. Primarily for alternating current applications (both pressure and vacuum), this "normally closed" valve is available in standard pipe sizes from ¼" through 2". Having only two moving parts, it assures a positive high-speed action with short plunger travel. Noncorrosive throughout, it can be controlled by a relay or a microswitch, allowing the designer the choice of a complete electrical system. It can be mounted in any position and operated continuously without harm to the valve or the solenoid. (Airmatic Valve, Inc., LE-12/4, 7317 Associate Ave., Cleveland 9, Ohio.)



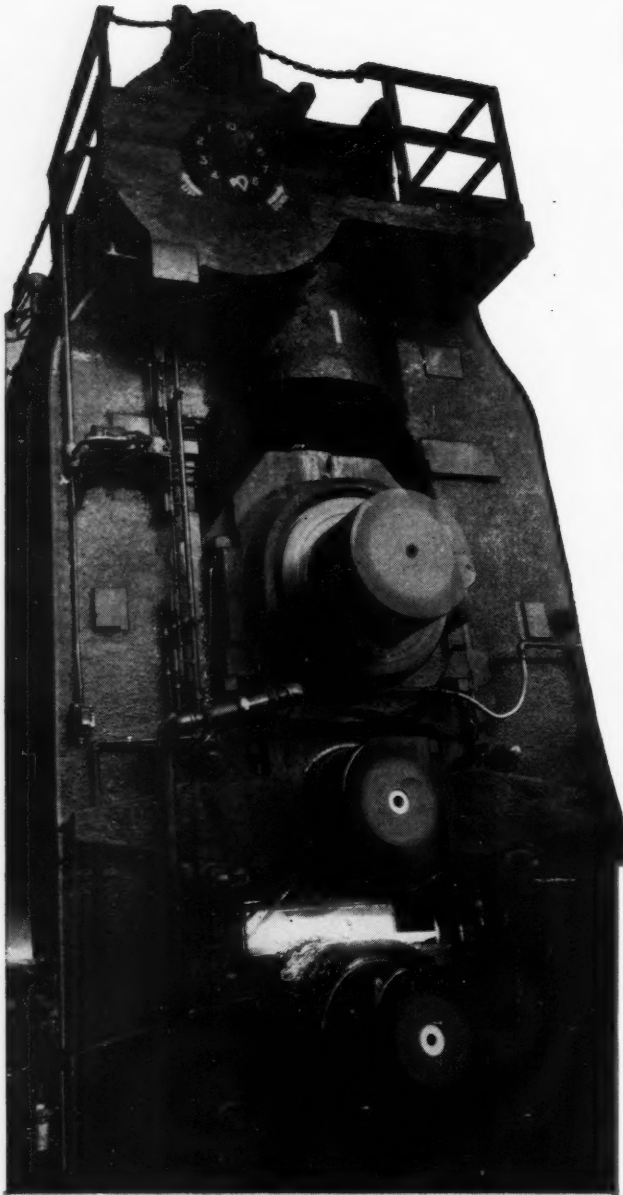
Corrosion-Resistant Exhaust Tubing. A permanently flexible, heavy-duty, vibration-absorbing, corrosion-resistant, stainless steel flexible exhaust tubing (see picture above) has been announced that is capable of withstanding constant exhaust temperatures up to 1250° F. without damage. It is available in two types: Type U-140-S, which incorporates a soft copper wire packing that functions to plate the interlocking flexible tubing joints while in use to provide maximum flexibility under extreme vibration and high operating temperatures; and Type U-120-S, of similar construction, which does not have a copper wire packing and, therefore, is lower in cost yet highly efficient. Both types are fabricated from Chromium-Nickel 302 Alloy Steel and designed to provide long service life with greatly reduced exhaust line maintenance costs. (Universal Metal Hose Co., LE-12/4, 2133 S. Kedzie Ave., Chicago 23, Ill.)

Overflow Warning System. A new, self-powered automatic signal horn has been designed to alert plant crews against overflow of petroleum, chemical, and petrochemical storage tanks during filling operations. Known as the Falcon Tank-Overflow Horn, the new float-activated unit can be heard more than 1,000 feet away. The device, designed for installation on top of bulk storage tanks, is powered by harmless carbon dioxide, Freon 12, nitrogen, or compressed air, and will sound a sharp two- to four-minute or longer warning to pumping crews on tankers or to land-stationed filling crews. (Falcon Alarm Co., Inc., LE-12/4, Summit, N. J.)

Preventive Maintenance of Diesels. A new, automatic instrument called the "Quantometer" has been developed to check the condition of diesel engines by a thorough analysis of crankcase oil. Using only a half-teaspoon of sample oil, the instrument provides a complete quantitative analysis in two minutes, recorded on a direct reading chart. Correlation of the analysis with known engine data then enables engineers to detect wear and other factors before there is a chance of engine damage. The instrument permits great savings in time over usual procedures and, since it detects elements to the millionth part, provides immediate data not readily obtained by other methods. A reading which deviates from a known standard is thus the earliest indication of incipient trouble. (Applied Research Labs., LE-12/4, 3717 Park Pl., Glendale, Calif.)

Explosion-Proof Vapor-Pressure Baths. A new line of explosion-proof Reid Vapor-Pressure Baths has been announced for use in

(Continued on p. 281)



HOW LEADOLENE* Klingfast and Spray Lubrication can increase Roll Neck Bearing Life

By using Leadolene Klingfast in a spray lubrication system pioneered by Brooks, roll neck wear can be substantially reduced. The system is designed to spray bearings and roll necks with a fluid lubricant through pneumatic atomizing nozzles which fan the lubricant over journal surfaces with adequate supply to the thrust collar. Grease grooves are eliminated to increase bearing load area, and bearing life is substantially extended. Remachining costs are reduced, lubricant consumption is cut down . . . *and considerable savings are gained through significant reductions in mill down time.* Write for Engineering Bulletin K-26.

**The I. P. Lubricant with Indestructible pH-ilm.*

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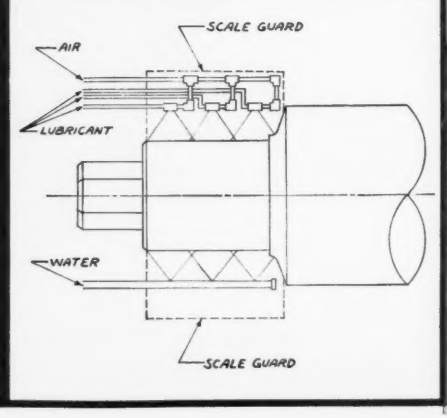
FOR PROOF OF LEADOLENE KLINGFAST'S SUPERIOR QUALITY AND COST REDUCING PERFORMANCE

In a lubrication study conducted over a period of one year on a 40" blooming mill, Brooks Leadolene Klingfast proved its efficient, cost reducing qualities. Best competitive E. P. Lubricants were consumed at the rate of twenty drums per week, and bearings wore out in three weeks' time. With Leadolene Klingfast, bearings showed no wear after sixteen weeks and only three drums were consumed per week.

Roll Neck Journal and Bearing Spray



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ASLE News Notebook

CORRECTION

The new industrial director elected at the April board meeting, Mr. C. T. Lewis is Lubrication Engineer with the Republic Steel Corporation and not U.S. Steel as erroneously reported in the notebook for May-June.

Executive Reports

A joint meeting of the Executive Committee, Membership Committee, and the Regional Vice-Presidents was held June 7, 1956 in Detroit. The duties of the Regional Vice-Presidents were defined and final plans for the 1956 membership campaign were approved. Each of the Vice-Presidents will choose one or more Area Representatives to assist him in fulfilling his duties. Among the duties assigned the four Regional Vice-Presidents were: to build membership, to organize educational courses, and to assist the Sections in their respective regions.

WESTERN REGION

Efforts in the Western Region are directed at starting a new Section in the Seattle-Portland area.* Another educational course is being planned for the region this year.

MID-WESTERN

Membership goals for the eight Sections in the Mid-West have been set. New Sections are planned for Duluth, Minn., Rockford, Ill., and the Dallas, Texas areas.*

CENTRAL

Although the Central Region has been established for only a few months, each of the Sections has been contacted and programs are being planned for the coming year. A new Section is being planned for the Columbus area in the near future.*

EASTERN

The Eastern Region welcomes a new Section, the Hudson-Mohawk Section, with approximately 30 members (*See Section News*). New Section plans include the Richmond, Va., area.* The Baltimore Section is planning to hold an educational course sometime during 1956-57.

*Members interested in working to create these new Sections should write their Regional Vice-President.

CANADIAN

No report.

ADMINISTRATIVE SECRETARY'S REPORT

Exhibit space rates for the 1957 Annual Meeting & Exhibit to be held at the Sheraton-Cadillac Hotel, Detroit, April 15, 16, and 17 have been established. These rates will be available through the National office.

New office equipment for the duplication of inter-Society documents and certain temporary publications has been installed in the national office. Refinements to our semiautomatic filing system will result in additional time savings through the incorporation of improved billing and handling techniques. This work is in progress.

Board Actions

To fill the vacant office of Vice President-at-Large, created by the succession of E. R. Booser to the office of President upon the death of W. Deutsch, the Nominations Committee proposed the name of J. O. McLean. No additional candidates were proposed by the board and Dr. McLean was elected. In clarifying the order of succession to office for April 1957, Article IX, Section 2-G of the By-Laws defines that the current Vice President-at-Large succeeds to the office of President, and that, "The President and each elected Officer of the Society shall hold office for a term of one year, or until his successor shall have been duly elected and shall have qualified, and shall assume his office at the close of the Annual Meeting of the members succeeding his election . . ."

The election of Dr. McLean created vacancy in the office of Eastern Regional Vice-President. Mr. M. E. Dougherty was proposed by the Nominations Committee to fill this vacancy. No additional candidates were presented from the floor, and Mr. Dougherty was elected to office.

Election of the new Nominations Committee is held yearly during the meeting of the June Board of Directors. Chairman of this committee is the Chairman of the Presidential Council, J. W. Hopkinson for this year, according to the By-Laws. Mr. Boyd and Mr. Fowler were elected to fill the remaining two places on this committee.

The name of the Industrial Advisory Committee was changed to *"Industrial Representative Committee"* to avoid misinterpretation of the function of this committee by agencies outside the Society.

Wording of Section I.B.1.(b) the document "Reorganization of ASLE Committee Structure" dated January 19, 1956, (See *Lubrication Engineering* May-June 1956, p. 207), was changed to, "Each year it shall be the responsibility of the Director-Sponsor to propose suitable chairmen . . .", by Board action.

Publication of *Lubrication Engineering* on a monthly basis commencing January 1, 1956 was approved by

←
J. O. McLean
Reynolds Metals Co.
Vice President-at-Large

→
M. E. Dougherty
Acheson Colloids Co.
Eastern Vice-President

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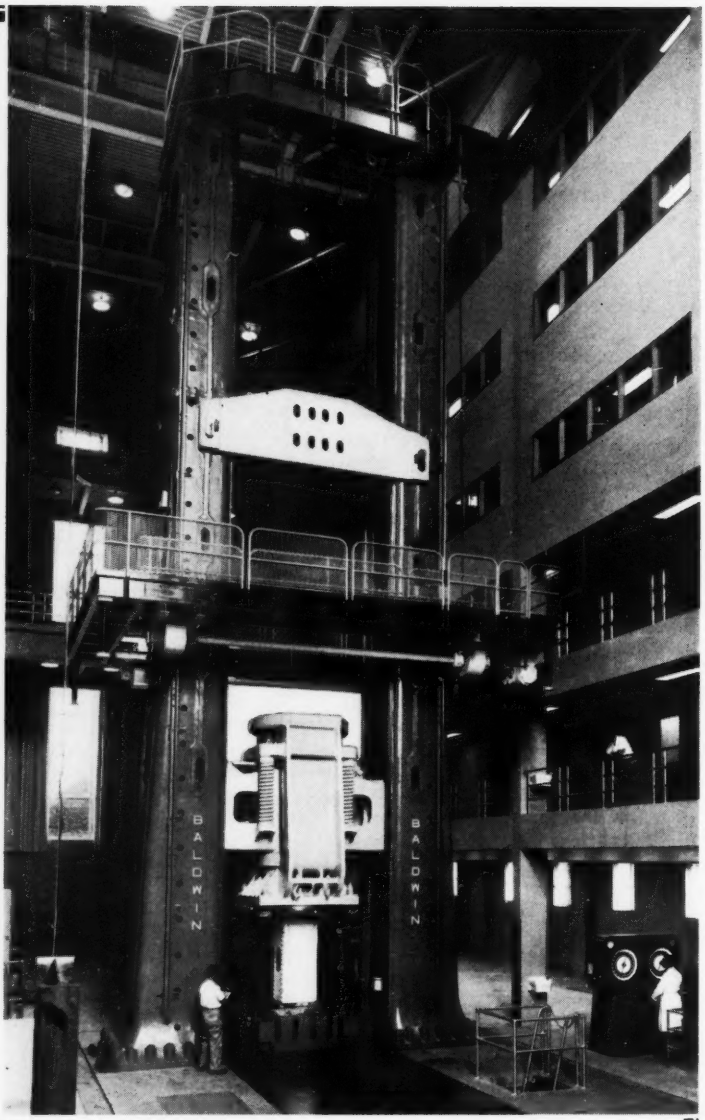
When engineers of Baldwin-Lima-Hamilton Corporation designed and built this mammoth 5,000,000 pound universal testing machine for Lehigh University, they realized from years of experience that extreme testing pressures could cause destructive "stick-slip" action in the test specimen grips and the loading screws.

That is why MOLYKOTE Lubricant was generously applied to both the grips and the screws before the first trial specimen was broken in this giant universal tester.

Baldwin engineers, as well as engineers throughout industry, have come to depend upon MOLYKOTE Lubricant in extreme pressure applications.

MOLYKOTE is manufactured from the purest molybdenum disulfide powder available to industry today. It is compounded under laboratory supervision to retain this purity in the manufacturing process and has achieved an enviable reputation for overcoming the toughest lubrication problems in industry.

MOLYKOTE Lubricant is distributed throughout the world, wherever industry faces the obstacles of providing adequate lubrication in extreme pressure and extreme temperature applications.



5,000,000 pound B-T-E Universal Testing Machine installed in Fritz Engineering Laboratory, Lehigh University, Bethlehem, Pa. Built by Baldwin-Lima-Hamilton Corporation, Eddystone, Pa.

If you are not receiving the new LUBRICATON NEWSLETTER, write today on your company letterhead and we will gladly add your name to our mailing list.

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the Board (See report of Editorial Committee, this issue). Subscription rates for the journal commencing January 1, 1956 will be increased to $6.00 per year on domestic and Canadian subscriptions and $7.00 per year for foreign subscriptions.

Buffalo, New York was selected as the site for the 1959 Annual Meeting to be held April 21, 22, and 23 based on the recommendations of the Annual Meeting Sites Committee. Cincinnati, Ohio is being considered for the 1960 meeting and New York City for the 1961 meeting.

President Booser has invited the National Railroad Lubrication Council (NRLC) to become affiliated with ASLE, working with the Technical Advisory Board in problems of mutual concern, as an industrial committee of the Society. Several basic differences in the By-Laws of the two groups must be resolved at a meeting of the Executive Committee of NRLC and ASLE representatives in the future.

To permit the inclusion of future groups having rules differing from the ASLE By-Laws the Board passed the following motion: "Since it is possible that existing Industry Lubrication Groups may become affiliated with ASLE as a sub-committee or group under the Technical Advisory Board, as outlined in the newly-adopted ASLE Committee structure, dated January 19, 1956, . . . when such a group is accepted by and affiliated with ASLE, that the existing organizational structure and by-laws of the group may be used as the controlling rules for the group, if approved by the ASLE Board of Directors."

To increase the value of the journal to the members and subscribers concerned primarily with the application and use of lubricants, Director Cichelli suggested the establishment of prize to be awarded for the best application-type article published in *Lubrication Engineering* each issue. The Board agreed with the idea expressed in Mr. Cichelli's letter and voted to establish the *"Wilbur Deutsch Memorial Award,"* to be awarded annually to the best practical paper published in *Lubrication Engineering*. Details of the award requirements will be worked out jointly by the Editorial and Awards Committees.

Mr. J. A. Brady, chairman of the Annual Meeting Committee, reported on the plans for next year's meeting in Detroit. Extensive effort is being directed at the Detroit industries to arouse interest and participation on the part of the maintenance and lubrication personnel among the supervisory levels at the annual meeting. Sessions are being shortened next year to permit the members and guests to see more of the exhibits. All registrants will be encouraged to visit the exhibit areas whenever technical sessions are not in progress.

Committee Reports

Committee chairmen have been selected for all of the committees except Hydraulics & Hydraulic Machinery, Education, Projects, Industry Relations, and Industrial Representative. (See ASLE Directory, this issue.)

JOURNAL BEARING RESEARCH

Instructions for revising the Journal Bearing Abstracts have been prepared and are being screened for use on the project.

ABSTRACTS

Rules for abstracting items for *Lubrication Engineering* are being circulated. Each Technical Committee will be asked to appoint a member to work with the Abstracts Committee.

PROGRAM

This committee is completely staffed and functioning on the program for the next year's meeting. Seventeen complete sessions are planned. The Speaker's Bureau Subcommittee is active under K. M. Holley.

EDITORIAL AND FINANCE

Projected costs and income were analyzed in a joint meeting of the Editorial committee and the Finance committee held May 24, 1956. The group recommended the publication of *Lubrication Engineering* on a monthly basis beginning January 1, 1957.

Technical Advisory Board

LIAISON COMMITTEES

The increased importance of liaison representatives for our intra-Society relationships is being considered by the TAB. Possible integration of this function within the TAB to improve communications and define activities more fully will be investigated.

TAB

Chairmen have been appointed for all technical committees except Hydraulics & Hydraulic Machinery. Four requests for technical information have been received and acted upon. Executive sponsors have been appointed for each technical committee. Following the decision of the National Machine Tool Builders Association to table the joint project on machine tool lubrication with ASLE, TAB has decided to set up an industry committee within the Society for this project. To study the inclusion of vertical industry committees within the technical committee structure, the executive committee of TAB has been assigned six basic industries to consider as follows: Machine Tool — S. R. Calish; Electrical — A. A. Raimondi; Steel — T. A. Marshall; Railroads — R. H. Josephson; Petroleum & Chemicals — R. G. Larson; Non-Ferrous Metals — E. M. Kipp.

June meeting of the Board of Directors held in Detroit. Shown, seated, are: W. P. Youngclaus, Jr., Administrative Secretary; J. W. Peterson, Treasurer; J. O. McLean, Vice President-at-Large; E. R. Booser, President; J. L. Finkelmann, Secretary; and J. W. Hopkinson, Chairman, Presidential Council. Standing are: R. K. Gould, Editor, **Lubrication Engineering** and Chairman, Editorial Committee; A. B. Wilder, Midwestern Vice President; D. W. Sawyer, Director; D. M. Cleaveland, Director; J. D. Lykins, Director; C. R. Schmitt, Director; C. T. Lewis, Director; R. F. McKibben, Central Vice President; J. H. Fuller, Director; S. R. Calish, Jr., Chairman TAB; and W. Lasky, Director.

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Springless Klozure (cutaway) shown on a BALL BUSHING (linear ball bearing) manufactured by Thomson Industries, Inc., Manhasset, New York.

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Klozure* Oil Seals Protecting bearings from dust and other contamination is as important in linear applications as it is in rotary bearing applications. That's why Thomson Industries, selected Garlock Klozure Oil Seals Model 71-A for their linear ball bearing. Thomson found that the unique design of the 71-A and its synthetic rubber sealing element made it ideal for their limited space, low pressure, grease retaining application.

Let us show you how one of "the Garlock 2,000" can help you . . . you can choose from two thousand different styles of packings, gaskets, and seals to meet all your needs. It's the only *complete* line . . . it's one reason you get *unbiased* recommendations from your Garlock representative. Call him today or write for Klozure Catalog 10.

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GARLOCK

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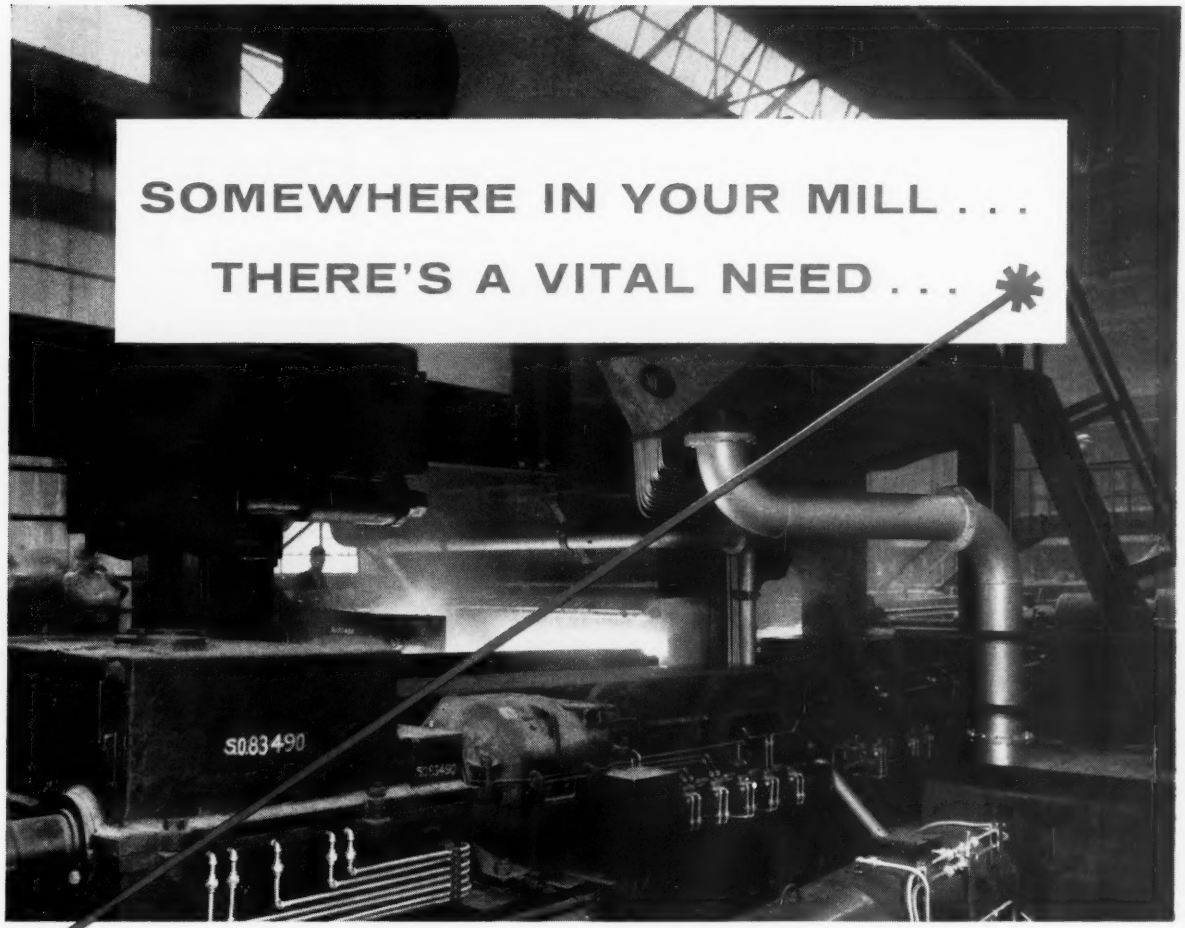

. . . for the kind of lubricant HOUGHTON can supply

MAYBE IT'S ONE OF THESE:

COSMOLUBE Multi-Purpose E. P.—treated Greases for Hot, Cold, Wet Spots.

TENAC Open Gear Lube that withstands high pressures and heat. Passes the 4-Gram Timken wear test.

STA-PUT mixed base greases and E.P.-treated adhesive oils.

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Somewhere you have a place for a better grease than you have yet found . . . a bearing, or gear set, or machine parts that are wearing faster than they need to—begging for that extra protection to prolong its operating life. And somewhere there's an oiler who is dissatisfied with the grease supplied to him, that has been causing trouble. He gets the blame when the lubricant is at fault.

Houghton has long had a reputation of making top-grade lubricants compounded for the specific use recommended by men who have made lubrication their life's work. A few of these are listed at the left; others are described in our Grease Booklet which is yours for the asking. E. F. Houghton & Co., 303 W. Lehigh Ave., Philadelphia 33, Pa. Plants also in Chicago, Detroit, San Francisco and Toronto, Canada.

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Meets **toughest** lubrication requirements!

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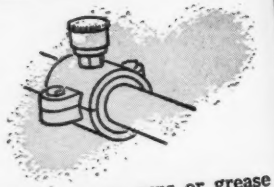
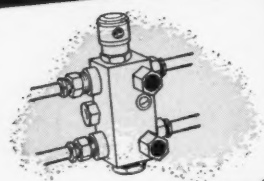
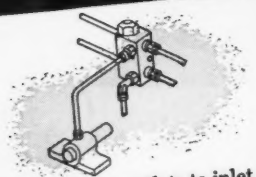


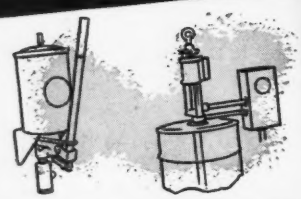
1. Remove grease cups or grease fittings.



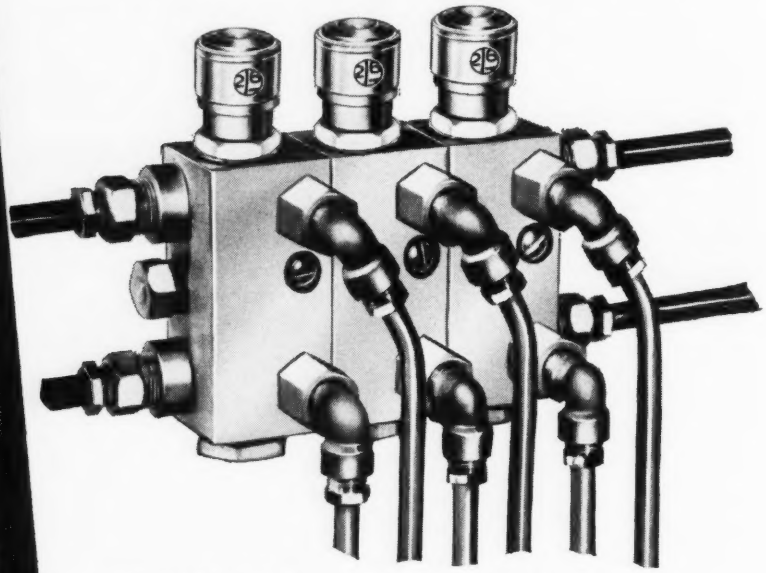
2. Connect each valve in system to its two lubricant supply lines.



3. Connect valve outlets to inlet of bearings. (Each valve serves two bearings.)



4. Provide central pump for supplying lubricant to system.



Alemite Type II Accumatic Valves meet big-volume requirements . . . handle difficult multiple-bearing lubrication under all conditions. Fully sealed for *clean* lubrication of power shovels, cement kilns, conveyors – any outdoor or indoor installation. Operate whether completely immersed in fluid . . . covered by dirt or grit . . . or protected by anti-corrosive paint. For fluid oil or light grease. Four sizes, delivering from .050 to .500 cu. in. of lubricant. Fully hydraulic – no springs to adjust or replace.

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LUBRICATION ENGINEERING

RESEARCH APPLICATION EDUCATION MAINTENANCE

Volume 12, No. 4
July-August 1956

Lubrication Engineer — A Definition

The scope and duties of the lubrication engineer are continually changing and broadening as the importance of lubrication is recognized by a greater share of management, production, and maintenance interests. In the past, the job of fitting this skill into the scheme of personnel classifications has been hap hazard, tending to recognize the place of the man in lubricant marketing by the title, Lubrication Engineer. Among these limited definitions is that found in the United States Dictionary of Occupational Titles, which recognizes the sales function of the Lube Engineer alone.

By contrast, the following excellent definition of the Lubrication Engineer's function and scope has been prepared by the ASLE technical committee on Lubrication Practices, under the chairmanship of K. S. Smiley, for incorporation into the next edition of the Dictionary of Occupational Titles.

> "A Lubrication Engineer is a person who, by professional training or equivalent experience, is qualified to apply the knowledge of engineering to the field of lubrication or lubricating science. He may be active in research, development, application, service and maintenance, consulting, technical sales, writing or teaching. In these activities, his responsibilities may involve direct or indirect participation in mechanical design, lubrication economics, lubricant formulation or application recommendations of all forms of lubricants in all types of equipment, machines, tools, or products with the objectives of obtaining optimum conditions with regard to wear, friction, power, corrosion, leakage, vibration, or other operating characteristics influenced by the lubricant. He is familiar with and may plan, participate in or supervise lubrication tests, practices, procedures, schedules, standards, requirements and/or other work involving lubricant storage, dispensing and reclaiming equipment."

This definition has been adopted by the Society at the Board of Director's meeting in Pittsburgh, April 6, 1956.

Lubrication Engineering salutes the Lubrication Practices Committee for this contribution to our understanding and interpretation of the Lubrication Engineer.

rdm

SAMUEL T. WELLMAN *was a horrified onlooker the day everything went wrong with the first open hearth furnace he had helped to build. Troubles reached their climax when the steel spilled out over molds, cars and tracks, welding everything into one mass as it chilled.*

This was in 1868. A year later, Wellman built a 5-ton open hearth furnace for the Bay State Iron Works, at South Boston. He used a much deeper bath and an arrangement of small ports, side by side with thin walls between, which gave a good mixture of gas and air. This furnace worked, and for years after produced ingots of the highest quality. It was America's first commercially successful open hearth furnace. Today, steel's greatest expansion is in open hearth capacity, increasing 36% between 1946-1955, to 110,234,160 net tons.

Great Names in Steel Making #II

Steel men respect success wherever met. But their special recognition is given to men and products that have helped the progress of steel.

An interesting example of this is the name "Gear Shield." In America there are mills in which the same gears have been lubricated with Gear Shield for 35 and 40 years. In consequence, the name has come to be so synonomous with satisfactory lubrication that other makers frequently refer to their lubricants as "gear shields" even though Gear Shield is the exclusive trade mark and product of The Ironsides Company.

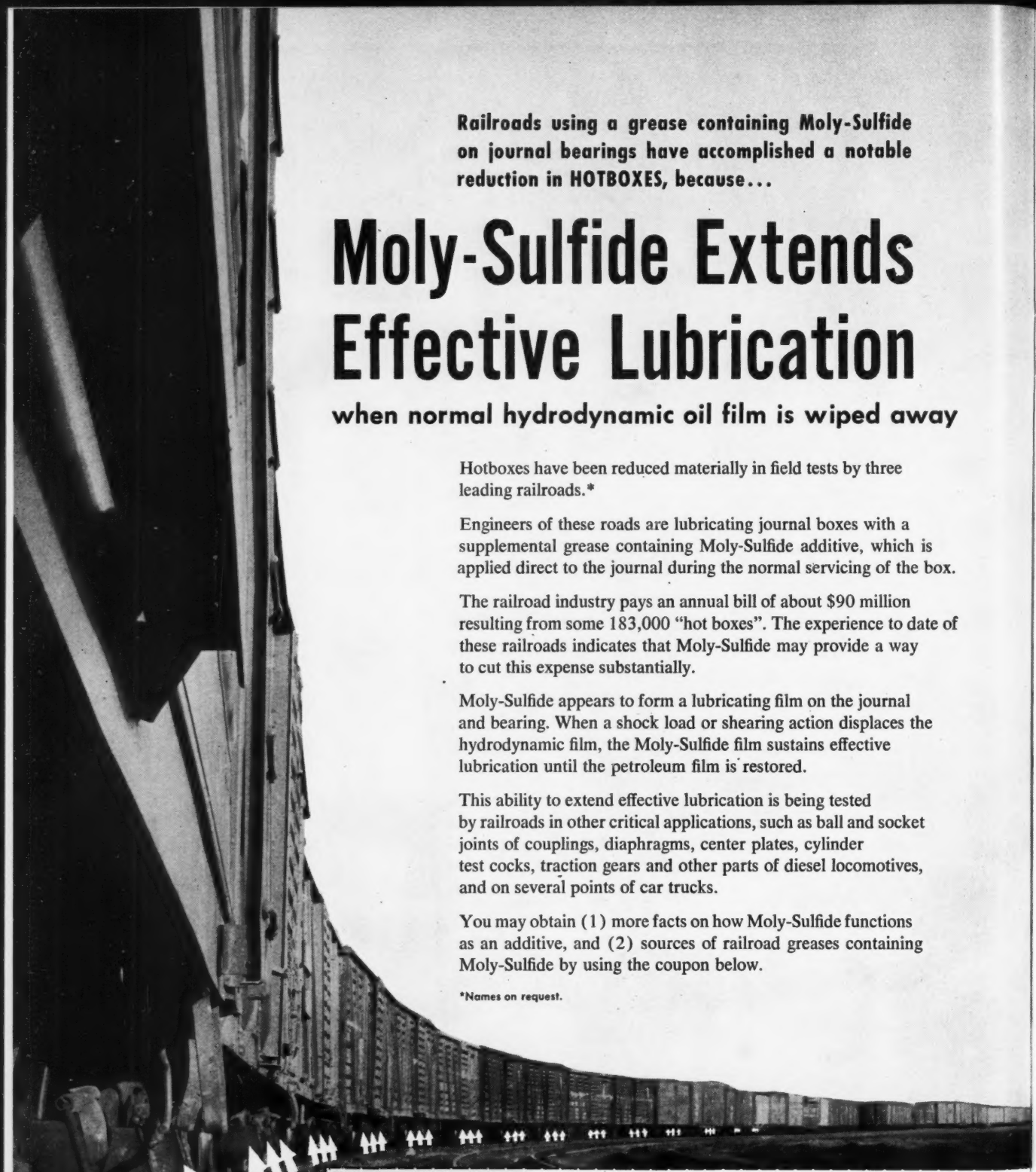
Paralleling developments in open hearth production since Samuel Wellman's first 5-ton furnace, Ironsides rolling mill lubricants have advanced far from the first heavy grease "shield," hand-paddled onto open gears. Encased gears now demand lubricants that can be poured, pumped and jetted. Free-running characteristics have become important in view of the enormous power consumption of today's big mills. At the same time, loads have increased until special Ironsides Shield is now being formulated for pressures as high as 25,000 psi. Shield for the roll necks is still being made of high melting point fatty base material, as it was 60 years ago, but is now formulated with close consideration to its pumpability. Water repellency, a consideration ever since the first rolling of hot steel, is of extreme importance in both roll neck and roller bearing shields.

In consequence, Ironsides engineers have become "custom tailors" of lubricants formulated for the specific conditions and preferences of the individual mill. They are accustomed to working closely with the superintendent, roller and lubrication engineer, on problems involving anything from a pail to tank car shipments.

If you have a problem, they'd like to help you lick it. Just address, or phone, The Ironsides Company, Columbus 16, Ohio.

By the makers of Palmoshield
"the palm tree that grows in Ohio"

Jos. MARGULÈS.



Railroads using a grease containing Moly-Sulfide on journal bearings have accomplished a notable reduction in HOTBOXES, because...

Moly-Sulfide Extends Effective Lubrication

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Boundary Lubrication Studies of Typical Fluoroesters

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The boundary-lubricating and wear-preventive properties of some new fluorinated diesters, which offer many advantages as high-temperature lubricants, have been investigated. These diesters were synthesized from aliphatic dibasic acids and nearly completely fluorinated alcohols. Friction and wear measurements were obtained using a "stick-slip" apparatus and a four-ball wear machine at temperatures from 77 to 400°F. The rubbing surfaces included hard steel, soft steel, and bronze. Fluoroesters containing typical antiwear or oiliness additives were also studied. For comparative purposes, results obtained with the familiar unfluorinated diester, bis(2-ethylhexyl) sebacate, are included.

The frictional properties of the two classes of diesters did not differ sufficiently to be of practical significance. However, the fluoroesters had better wear-preventive properties, especially at higher temperatures. Friction was markedly reduced by the addition of one percent stearic acid to either type of diester. The addition of two percent tricresyl phosphate was more effective in the fluoroester as an antiwear agent for hard steel on hard steel; approximately the same low wear rates were observed at 140, 266, and 400°F.

The boundary-lubricating ability of the fluoroesters and their excellent response to conventional additives invite their application as primary ingredients of stable high-temperature oils and greases.

INTRODUCTION

This report concerns the boundary-lubricating and wear-preventive properties of certain partially fluorinated esters.[1] Diesters prepared from the aliphatic dibasic acids and telomer alcohols of tetrafluoroethylene and methanol were shown to be the most promising for use at temperatures as high as 500° F.[2] These diesters possess good hydrolytic and thermal stabilities, exceptional resistance to atmospheric oxidation at high temperatures, and good resistance to oil mist explosion hazards. Typical compounds of this class are bis (1H, 1H, 5H-octafluoropentyl) glutarate and bis (1H, 1H, 7-H-dodecafluoroheptyl) 3-methlyglutarate. Following the convenient abbreviated system of nomenclature used previously, [1,2] the above compounds will be called bis (ψ'-amyl) glutarate and bis (ψ'-heptyl) 3-methylglutarate, respectively. The boundary-lubricating and wear-preventive properties of these representative fluorinated diesters will be compared with those of a familiar unfluorinated aliphatic diester, bis (2-ethylhexyl) sebacate.

MATERIALS & EXPERIMENTAL METHODS

The partially fluorinated compounds studied were synthesized at this Laboratory.[1] The bis (2-ethylhexyl) sebacate was vacuum distilled and then percolated through a column of activated "Florisil" and alumina to remove polar impurities. Some physical properties of the purified fluids are given in Table I.

Friction measurements were made on a modified Bowden-Leben or "stick-slip" machine[3] between a uniformly sliding plane specimen (the platen) and an elastically-loaded and restrained sphere (the slider). Descriptions have been published of the machine used at this Laboratory[4] and of the mechanoelectronic transducer recording system[5] developed for it. Boundary lubrication was maintained by using sliding speeds of 0.01 cm/sec and a load of 800 grams. At room temperature, the platen and slider were maintained at 78°F. ± 2°F.; at more elevated temperatures, the platen was within ± 10°F. of that reported.

Wear measurements were made with the Precision Scientific Company's version of the Larsen-Perry four-ball wear machine.[6] The construction, operation, and peculiarities of the Larsen-Perry machine have been discussed by Clinton.[7] The calibrated helical spring system normally

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Table I

Physical Properties of Pure Liquids Studied

Compound	Boiling Point (°F at 0.5 mm Hg)	Freezing Point (°F)	Viscosity (cs) at 210°F	Viscosity (cs) at 100°F	Viscosity (cs) at 0°F	ASTM Slope (68° to 210°F)	d_4^{20}	Surface Tension (dynes/cm) at 20°C
Bis(ψ'-amyl) glutarate	273	— 17	2.65	13.7	349.	0.88	1.598	27.5
Bis(2-ethylhexyl) sebacate	450 (a)	—67	3.32	12.6	187.	0.71 (c)	0.917 (d)	31.1
Bis(ψ'-heptyl) 3-methyl glutarate	311	—58 (b)	3.70	26.4	1280.	0.88	1.648	25.6
Bis(ϕ'-octyl) 3-methyl glutarate	293	61	2.80	18.3	——	0.95	1.689	19.5
1,6-Bis(ψ'-heptoxy) hexane	291	—58 (b)	2.59	13.0	332.	0.88	1.578	25.3

(a) 1-2 mm Hg, (b) Sets to glass at temperature indicated, (c) —40° to 210° F., (d) Interpolated

used to measure the frictional force was replaced by a system employing a pair of electronic strain gages. This system has proved reliable and sensitive, has eliminated the necessity of changing springs to cover the range of frictional forces, and has made possible a faster and easier determination of these forces. The applied loads were accurate to ± 0.1 kg, and the temperature of the fluid in the four-ball cup was controlled to ± 2°F. In each experiment four new balls were used. The speed of the rotating ball was approximately 600 rpm, and the time of each test was two hours.

The ball sliders used in the friction machine, and the balls used in the wear machine, were degreased by rinsing them several times in hot ACS benzene. The flat platens were abraded under running water with 320A, 400A, and 600A grit silicon carbide paper; they were next held under flowing tap water a short time with grease-free tongs; they were then rinsed with ACS acetone. Because of the high volatility and low wettability of the fluoroesters, it was necessary to make friction measurements at elevated temperatures on dish-shaped platens in order to maintain a pool of liquid over the entire surface. These platens were made from bars ⅜" thick, the working surface being a flat circular area one inch in diameter which had been recessed to a depth of 1/16". These platens were abraded dry in a lathe with 400A and 600A grit silicon carbide paper. Before measurements of friction were made, each platen was degreased with ACS benzene. To test for the absence of contamination, a dry friction measurement was made just prior to placing the lubricant on the platen.

STUDIES WITH THE "STICK-SLIP" MACHINE

Comparisons of the boundary friction of various metal combinations lubricated with the two fluorinated diesters and with bis (2-ethylhexyl) sebacate are given in Table II. The static coefficient of friction (μ_s) is given for both the first and tenth traverses over the same wear track for five of the metal combinations. It had been shown in a recent investigation[8] that repeated traverses in one direction were useful in demonstrating the growth of a friction-reducing film resulting from a tribochemical reaction.

In every instance (Table II) friction was characterized by large and continued stick-slips. When this type motion occurs, the relative velocity between the slider and platen may be of the order of a few centimeters per second during the slip even though the velocity of the driven platen is only 0.01 cm/sec. Because of this relatively high slip

Table II

Static Coefficient of Friction (μ_s) for Various Metal Combinations Lubricated with Fluorinated or Unfluorinated Diesters (Data Obtained in "Stick-slip" Machine at 77°F)

Sphere and Platen Combination	Lubricated with Bis(2-ethylhexyl) sebacate		Lubricated with Bis(ψ'-amyl) glutarate		Lubricated with Bis(ψ'-heptyl) 3-methyl glutarate	
	1st Traverse	10th Traverse	1st Traverse	10th Traverse	1st Traverse	10th Traverse
Hard Steel on Hard Steel	0.18	0.21	0.22	0.33	0.18	0.26
Bronze on Hard Steel	0.22	0.21	0.29	0.33	0.25	0.24
Hard Steel on Naval Brass	0.50	0.50	0.40	0.42	0.34	0.38
Bronze on Naval Brass	0.52	0.51	0.45	0.48	0.38	0.38
Hard Steel on 1020 Steel	0.22	0.40	0.29	0.26	0.29	0.23
Stainless Steel on 1020 Steel			0.29			
Monel on 1020 Steel			0.25			
Bronze on 1020 Steel	0.21		0.25			
Soft Steel on 1020 Steel			0.31			
Aluminum (17 ST) Alloy on 1020 Steel	0.23		0.23			
Copper on 1020 Steel			0.28			

velocity, the kinetic coefficient of friction (μ_k) may include a hydrodynamic contribution. Therefore, whenever this type of motion occurred, μ_s was considered to be the more reliable measure of the boundary-lubricating qualities. The values of μ_s reported in Table II were computed from the maximum value of the frictional force in each relaxation oscillation of the suspension.

A larger value of μ_s was observed with each lubricant when the platen was naval brass rather than either type of steel. This occurred when the slider was either hard steel (SAE 52100) or bronze, and may be attributed to the fact that μ_s for the corresponding dry system was higher. Bis(2-ethylhexyl) sebacate was slightly more effective as a boundary lubricant than the two fluoroesters studied for either hard steel or bronze sliding on hard steel. It was a less effective lubricant than the fluoroesters for hard steel or bronze on naval brass. When the three diester fluids were used to lubricate hard steel on soft steel (SAE 1020), μ_s was lowest with the unfluorinated diester during the first traverse and highest with this diester during the tenth traverse. This increase in μ_s with the number of traverses was investigated further. No significant changes in the values of μ_s were obtained by using freshly percolated samples of bis(2-ethylhexyl) sebacate. Neither did changes in relative humidity from 20 to 45 percent nor the dissolution in the oil of 0.5 percent of phenothiazine affect the value of μ_s. Examination of the photomicrographs taken of the wear tracks on the soft-steel platens after ten traverses revealed that more wear had occurred with the sebacate than with either fluoroester.

Table II also gives values of μ_s for a single traverse using a series of metal sliders against a soft-steel platen lubricated with bis(ψ'-amyl) glutarate. "Stick-slip" motion was always observed, and μ_s did not vary greatly among these metal combinations. In order to determine how such metal combinations are lubricated by an unfluorinated diester, a bronze slider and an aluminum-alloy slider were made to traverse a soft-steel platen lubricated with bis(2-ethylhexyl) sebacate. The resulting friction in the first traverse was essentially that observed with bis(ψ'-amyl) glutarate.

In an attempt to learn something about the effect of the constitution of the fluorinated fluids on their boundary lubricating properties, μ_s was measured in the same manner for a series of fluorinated liquids. The additional liquids were: (a) bis(ϕ'-octyl) 3-methyl glutarate (the ϕ'-compounds have three substituted fluorine atoms on the ω carbon atom instead of two as in the ψ' compounds); (b) 1,6-bis(ψ'-heptoxy) hexane, a partially fluorinated diether; and (c) a perfluorinated kerosene.

The values of μ_s measured during a series of repeated traverses of a hard-steel slider over a lubricated soft-steel platen are given in Figure 1. Friction increased markedly with repeated traverses when either bis(2-ethylhexyl) sebacate or the fluoroether was used as the lubricant, and it either remained constant or decreased slightly when the fluoroesters or perfluorokerosene were used. Although μ_s in the presence of bis(2-ethylhexyl) sebacate was less than with either bis(ψ'-heptyl) 3-methyl glutarate or bis-(ψ'-amyl) glutarate during the first traverse, after five traverses friction was higher with this unfluorinated ester than with any of the fluoroesters. After ten traverses, μ_s with the fluoroesters ranged between 0.20 and 0.25, whereas μ_s reached 0.40 with the sebacate. The differences in frictional behavior of the three fluoroesters were small, probably caused by differences in the lubricity of trace amounts of hydrolysis products. Values of the coefficients of friction of the fluorinated diether and bis(2-ethylhexyl) sebacate were nearly the same. Perfluorokerosene acted much like the fluoroesters; the slightly lower friction being evidence, presumably, of a lesser purity.

Comparable friction measurements for the same liquids lubricating hard steel sliding on brass were higher than those for hard steel sliding on soft steel with each liquid. The static coefficient of friction increased during ten successive traverses (from 0.35 to 0.65) when the ether was used, similar to the increase with steel on steel. However, friction with bis(2-ethylhexyl) sebacate was practically constant during successive traverses but at the high value of 0.50. When perfluorokerosene was used, μ_s decreased with repeated traverses from 0.50 to 0.35. With bis(ψ'-heptyl) 3-methyl glutarate and bis(ψ'-amyl) glutarate, μ_s was nearly constant from one to ten traverses at 0.35 and 0.40 respectively; with bis(ϕ'-octyl) 3-methyl glutarate, μ_s decreased slightly (0.30 to 0.25). Thus, the ψ'-esters appear to be more effective boundary lubricants for hard steel sliding on brass than the unfluorinated ester or the fluorinated ether but not quite as effective as the ϕ'-ester. Some of the differences in the frictional behavior of lubricated soft-steel and brass platens probably are caused by the effects on the metals of trace impurities in the liquids. In addition, there are contributory differences in the dry friction and in the durability of the oxide coatings formed.

Effect of Additives

Evidently these liquids often will require a friction-reducing or oiliness additive to function satisfactorily as a boundary lubricant. Several compounds which are fre-

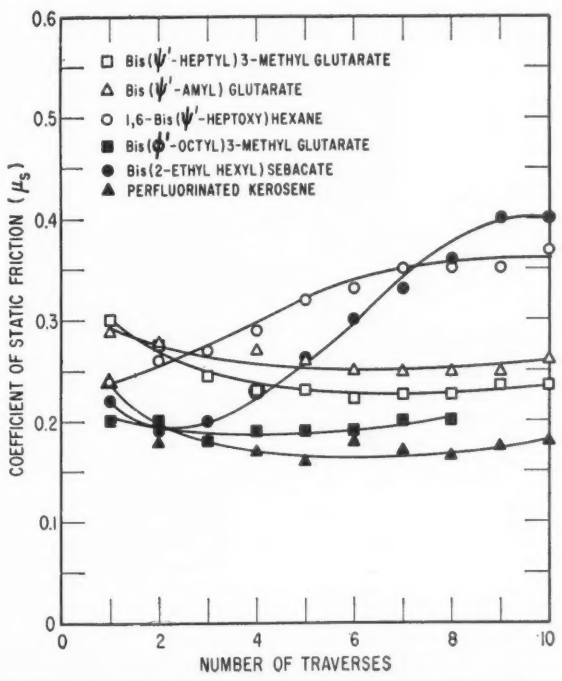

Figure 1. Effect of number of traverses on μ_s for hard steel on soft steel lubricated with various fluorinated liquids (all measurements at 77° F.).

quently employed as lubricant additives were dissolved in bis(2-ethylhexyl) sebacate to determine their effect on friction. These compounds were: a chemical polishing agent, tricresyl phosphate;[9] an anti-oxidant, phenothiazine;[10] and an oiliness agent, stearic acid. The results obtained with these compounds in lubricating hard steel on soft steel are given in Table III. Neither 2.0 percent by weight of tricresyl phosphate nor 0.5 percent of phenothiazine decreased μ_s at 77°F. by more than 10 percent in one or ten traversals. Approximately the same result was found when 2.0 percent of tricresyl phosphate in bis(ψ'-amyl) glutarate was used to lubricate the same metals. The addition of 1.0 percent of stearic acid to the sebacate resulted in an appreciable reduction in friction.

Table III

Effect of Additives in Diesters on the Static Coefficient of Friction for Hard Steel on Soft Steel (Data obtained at 77°F)

Additive	Bis(2-ethylhexyl) Sebacate		Bis(ψ'-amyl) Glutarate	
	1st Traverse	10th Traverse	1st Traverse	10th Traverse
None	0.22	0.40	0.29	0.26
0.5 Percent Phenothiazine	0.20	0.39	——	——
2.0 Percent Tricresyl Phosphate	0.20	0.36	0.22	0.23
0.5 Percent Phenothiazine + 4.8 Percent Tricresyl Phosphate	0.20	0.32	——	——
1.0 Percent Stearic Acid	0.15	0.11	Insoluble at 77°F	

Effect of Temperature (Without Additives)

The effect on μ_s of adding 1.0 percent of stearic acid to bis(ψ'-amyl) glutarate could be observed only at temperatures above 165°F. because of its low solubility in these fluoroesters. Before studying the effect of additives at elevated temperatures, it was expedient to investigate the influence of temperature on the lubricating properties of the non-additive liquids. In these experiments, friction was measured at 77, 200, 300, and 400°F. for a single traverse of a hard-steel slider over a soft-steel platen, as the platen was heated and again as it cooled. The fluids studied were the same as those shown in Figure 1, except for perfluorokerosene which was omitted because of its high volatility. By using the dished platens containing a deep enough pool of liquid to prevent evaporation to dryness or to prevent areas from being uncovered by the non-spreading liquid, friction measurements could be made on oil-covered platens at high temperatures.

With each liquid, the average value of μ_s was slightly lower at 77°F. than it was during the first traverse of a hard-steel slider over a flat soft-steel platen. The small difference in μ_s was probably the result of differences in the cleaning and polishing techniques used. There was little difference in effectiveness among the lubricants as the temperature was increased from 77 to 300° F. However, at 400°F. the fluorinated ether and bis(ψ'-amyl) glutarate caused the lowest friction ($\mu_s \approx 0.28$) and bis(2-ethylhexyl) sebacate the highest ($\mu_s \approx 0.43$); intermediate values of about 0.38 were obtained with bis(ψ'-heptyl) 3-methylglutarate and bis(ϕ'-octyl) 3-methylglutarate. Upon cooling the system, μ_s did not always return to its initial value. The diether behaved nearly reversibly, the sebacate showed only a slight permanent rise in μ_s, and the fluoroesters all exhibited a still greater increase over the initial room-temperature value.

At elevated temperatures, atmospheric oxidation often changes the lubricating properties of liquids. Therefore, bis(ψ'-amyl) glutarate was charged into a pyrex oxidation-stability cell maintained at 392°F. Air was continually bubbled through the liquid in which clean strips of copper, cold-rolled steel, and duralumin were immersed. At suitable intervals samples of a few milliliters each were removed from the oxidation cell and studied with the stick-slip machine. Single traverses were made at 77, 200, 300, and 400°F. with hard-steel and bronze sliders on soft-steel dished platens flooded with the oxidized ester. In several instances measurements were made on the liquid or solid lubricant residue after cooling the platen to 77°F. In these experiments stick-slip behavior did not always occur, particularly when bronze sliders were used. Therefore, the values of μ_s given in Table IV are the initial values which are not as reproducible as the average static coefficient of friction.

Friction was usually lower at all temperatures with each oxidized sample than it was with the unoxidized ester for both hard steel and bronze sliding on soft steel. However, increasing the oxidation period from 19 to 258 hours had little effect on μ_s. Either as much friction-reducing material had been generated in the first 19 hours as would adsorb on the steel, or else the sample of fluoroester had contained a less stable constituent which had ceased decomposing in that time. In general, μ_s for both the oxidized and unoxidized fluoroester increased slightly with in-

Table IV

Effect of Time of Exposure to Oxidation of Bis(ψ'-amyl) glutarate on Static Friction (μ_s) (Data Obtained in First Traverse)

Hours of Exposure to Oxidation* at 392°F	Initial μ_s for Hard Steel on Soft Steel				Initial μ_s for Bronze on Soft Steel			
	77°F	200°F	300°F	400°F	77°F	200°F	300°F	400°F
0	0.27	0.29	0.29	0.36	0.36	0.42	0.44	0.44
19	0.18	0.27	0.27	0.28	0.33	0.34	0.38	0.40
46	0.21	0.22	0.24	0.25	——	——	——	——
91	0.22	——	——	——	0.28	——	——	——
166	0.20	——	——	0.31	0.35	0.29	0.36	0.37
216	——	——	——	——	0.38	0.35	0.40	0.33
258	0.22	0.24	0.26	0.31	0.32	——	——	0.43

*Oxidation by aeration in glass cell containing strips of copper, SAE 1020 steel, and duralumin.

Table V

Effect of Temperature and of Additive on μ_s for Hard Steel on Soft Steel Lubricated with Diesters

Temp. °F	Initial Static Coefficient of Friction (μ_s) First Traverse						
	Additive to Bis(2-ethylhexyl) sebacate				Additive to Bis(ψ'-amyl) glutarate		
	None	0.5 Percent Phenothiazine	2.0 Percent Tricresyl Phosphate	1.0 Percent Stearic Acid	None	2.0 Percent Tricresyl Phosphate	1.0 Percent Stearic Acid
77	0.28	0.27	0.24	0.12	0.27	0.22	——
200	0.33	0.32	0.31	0.08	0.29	0.25	0.08
300	0.32	0.34	0.31	0.10	0.29	0.26	0.09
400	0.32	0.36	0.32	0.20	0.36	0.35	0.08
300	0.26	0.34	0.21	0.23	0.44	0.36	0.04
200	0.26	0.35	0.18	0.20	0.35	0.32	0.07
77	0.20	0.24	0.18	0.17	0.26	0.25	——

creasing temperature. This fluoroester was also a better boundary lubricant for hard steel on soft steel than for bronze on soft steel.

After measuring μ_s for the oxidized diester at 400°F., the platen was allowed to cool to room temperature. The effect of the heat was sometimes sufficient to evaporate all the liquid, leaving an oxidation residue which varied from a grease to a lacquer. Lower friction and less wear were generally observed with the cooled residue, whether liquid or solid. For example, there was much less transfer of bronze to the steel platen in five traverses over the same wear track lubricated with the mobile residue of the glutarate, which had been oxidized for 216 hours, than in a single traverse on this substance before heating.

Effect of Temperature (With Additives)

After establishing the effect of temperature on the frictional behavior of the nonadditive diesters, μ_s was measured at elevated temperatures using bis(ψ'-amyl) glutarate or bis(2-ethylhexyl) sebacate containing one of the three additives discussed earlier. Data for hard steel on soft steel are given in Table V, and for bronze on soft steel in Table VI. The values given are the initial static coefficients of friction. Measurements were made during a single traverse as the platen was heated and again as it cooled. It was usually necessary to add some lubricant (ca. 0.5 ml) after the 400° F. measurement to compensate for evaporation losses. Over the temperature range studied, there were no practical differences between the nonadditive fluorinated and unfluorinated diesters. Both were more effective as boundary lubricants for hard steel on soft steel than for bronze on soft steel. Of the three types of additives studied, only stearic acid appreciably lowered the boundary friction. It is well known that stearic acid greatly reduces friction at ordinary temperatures by forming on a solid surface a close-packed adsorbed monolayer[11] which decreases the adhesion between the solids.[12, 13] Both diesters, with or without additives, usually exhibited increasing boundary friction with rise in temperature. This effect was not entirely reversible, which indicated that either the lubricant or metal interface was slightly altered chemically during the short exposure to these temperatures.

STUDIES WITH THE FOUR-BALL WEAR MACHINE

The variables that can be examined readily with the four-ball machine are load, temperature, time of run, rotational speed, and composition of the four balls. Of primary importance in this investigation were the effects of load and temperature on the wear-preventive properties of bis(2-ethylhexyl) sebacate, bis(ψ'-heptyl) 3-methylglutarate, and these same liquids containing various additives. The loads selected for these experiments were 2.5, 5, 10, 20, and 50 kg. At loads less than 2.5 kg the results are affected by the viscosity of the oil, and hence boundary-lubricating conditions are not dominant. The wear scars are also difficult to measure and reproduce at this and smaller loads. The highest load chosen was 50 kg because of the design limitations of the machine used. These loads correspond to calculated initial pressures of 131,000 psi at 2.5 kg to 354,000 psi at 50 kg for the hard-steel balls.

Wear measurements were made at 140, 266, and 400°F. Preliminary studies showed that if the machine

Table VI

Effect of Temperature and of Additive on μ_s for Bronze on Soft Steel Lubricated with Diesters

Temp. °F	Initial Static Coefficient of Friction (μ_s) First Traverse						
	Additive to Bis(2-ethylhexyl) sebacate				Additive to Bis(ψ'-amyl) glutarate		
	None	0.5 Percent Phenothiazine	2.0 Percent Tricresyl Phosphate	1.0 Percent Stearic Acid	None	2.0 Percent Tricresyl Phosphate	1.0 Percent Stearic Acid
77	0.33	0.36	0.34	0.15	0.35	0.30	——
200	0.36	0.39	0.34	0.15	0.37	0.33	0.15
300	0.42	0.34	0.38	0.23	0.45	0.38	0.16
400	0.37	0.45	0.34	0.33	0.46	0.54	0.25
300	0.34	0.33	0.32	0.37	0.48	0.45	0.27
200	0.38	0.30	0.28	0.36	0.40	0.42	0.15
77	0.28	0.26	0.30	0.32	0.36	0.35	——

was operated where the ambient temperature was about 77°F., the lowest practical temperature obtainable, without the use of coolants, was 140°F. It was found that with a 50-kg load, frictional heat would raise the bulk temperature of bis(2-ethylhexyl) sebacate from 77 to 132°F. in two hours. Because friction is a function of the load, the oil temperature would differ for the various loads if experiments were conducted below 132°F.; hence, 140°F. was the lowest temperature selected. The 266°F. temperature was chosen because oils often are required to operate in this range, and because comparable data on other oils have been reported at this temperature. Some measurements were made at 400°F. to assess the possibilities of the fluoroesters as high-temperature lubricants.

The solid Hertz line shown in the following figures gives the diameter of the elastic deformation of the hard steel balls for each corresponding applied load. The final average pressure on the wear scar can be estimated readily from the dashed lines of equal pressure.

Effect of Load

A graph of wear-scar diameter vs the applied load at 140° F. for bis(ψ'-heptyl) 3-methylglutarate is compared with that for bis(2-ethylhexyl) sebacate in Figure 2. The discontinuity in the sebacate curve at the 10-kg load was probably caused by a breakdown of the lubricant film. Examination of the wear scars produced with the 20- and 50-kg loads revealed a tenacious dark brown deposit near the leading edge of the scar. This deposit was surrounded by a lighter brown area, and the fluid itself was discolored. These deposits were either the breakdown products of the sebacate or the results of a chemical reaction between these products and the metal. They formed at the areas of contact between cup and spindle balls, were abraded off, carried by the spindle ball, and deposited at the leading edge of the next wear scar. No deposits could be seen on the scars themselves. At loads of 2.5 and 5 kg, a brown deposit appeared on the scars; but no deposit was observed outside the scar, nor was the fluid discolored. At the 10-kg load either of these conditions could occur. No deposits were formed with bis(ψ'-heptyl) 3-methylglutarate, and the final pressure at each load is about 50,000 psi. At all loads below 50 kg, wear was smaller with the fluoroester.

Similar experiments were repeated at 266°F. and the results are plotted in Figure 3. In the low-load region the wear with bis(2-ethylhexyl) sebacate was much greater at 266°F. than at 140°F., but at high loads wear was nearly

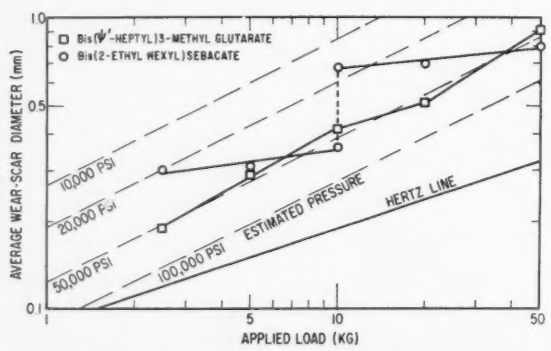

Figure 2. Comparison between wear rates using fluorinated and unfluorinated diesters (data obtained at 140°F.; hard steel on hard steel).

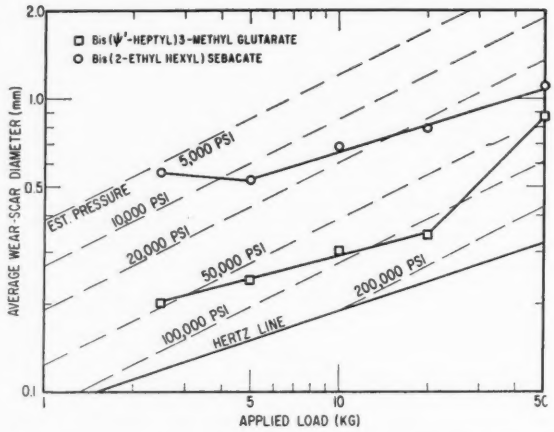

Figure 3. Comparison between wear rates using fluorinated and unfluorinated diesters (data obtained at 266°F.; hard steel on hard steel).

equal at these temperatures. These results suggest that the viscosity of the oil is a factor in determining wear at the lower loads. The 140 and 266°F. graphs for the fluoroester nearly coincide at the 2.5 and at the 50-kg loads. At intermediate loads, less wear occurred at 266°F. Evidently, the decrease in viscosity with rise in temperature cannot account for these results. Probably a chemical product of oxidation or hydrolysis of the fluoroester was developed at the higher temperature which caused the reduction in wear. It was more effective as the applied loads were increased until the final pressure reached a maximum of 130,000 psi at 20 kg. At the 50-kg load the film broke down and the final pressure was reduced to 50,000 psi. Much less wear occurred at 266°F. with the fluoroester than with the sebacate, although at the highest load the difference was small.

Effect of Temperature

When the temperature of the fluorinated diester was increased to 400°F., a large increase in the rate of wear resulted. The wear-scar diameters were 0.29, 0.37, 0.45, 0.87, and 1.25 mm, with applied loads of 2.5, 5, 10, 20, and 50 kg, respectively. Additional wear measurements were made at 212 and 329°F. using a 20-kg load. The wear-scar diameters are plotted in Figure 4 as a function of the temperature. The minimum wear rate indicated at 266° F. suggests that the mild wear preventive generated by this diester increased in concentration with increasing temperature, but at temperatures above 266°F. it became

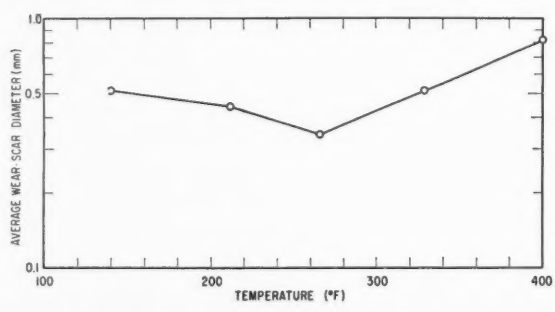

Figure 4. Effect of temperature on wear rate at 20 kg. load using bis (ψ'-heptyl) 3-methylglutarate (data obtained with hard steel on hard steel).

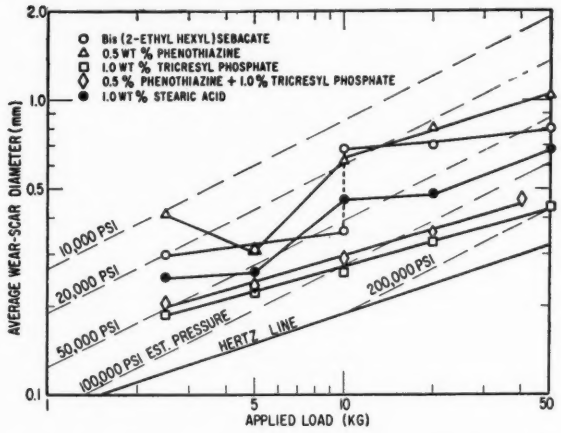

Figure 5. Effect of additives in bis(2-ethylhexyl) sebacate on wear rate of hard steel on hard steel (data obtained at 140°F.).

less effective in preventing wear. This may be due either to desorption or because the product became too corrosive to the steel; the former possibility is more likely.

Effect of Additives

The effect of additives on the wear-preventive properties were investigated next. Plotted in Figure 5 are the results obtained at 140°F. with bis(2-ethylhexyl) sebacate containing (a) no additive, (b) 1 wt. percent stearic acid, (c) ½ percent phenothiazine, (d) 1 percent tricresyl phosphate, and (e) ½ percent of phenothiazine plus 1 percent tricresyl phosphate. The effect of phenothiazine was to increase wear slightly at high loads. The increased wear may be explained by the fact that the antioxidant decreased the rate of formation of the oxidation products which are beneficial in preventing wear. Hence, the final pressure at the 50-kg load decreased from 65,000 to 35,000 psi with the addition of phenothiazine. Tricresyl phosphate greatly improved wear-reducing properties of this diester. The resulting curve of wear-scar diameter vs. load was a straight line having a smaller slope than the lines of equal pressure. Thus, a higher final pressure was obtained as greater loads were applied, increasing from 50,000 psi at 2.5 kg to almost 200,000 psi at 50 kg. When 1 percent of tricresyl phosphate and ½ percent of phenothiazine were used together, the resulting wear vs. load curve was slightly displaced above the curve for the tricresyl phosphate alone. The addition of 1 percent of stearic acid decreased the amount of wear but not to the same extent as tricresyl phosphate.

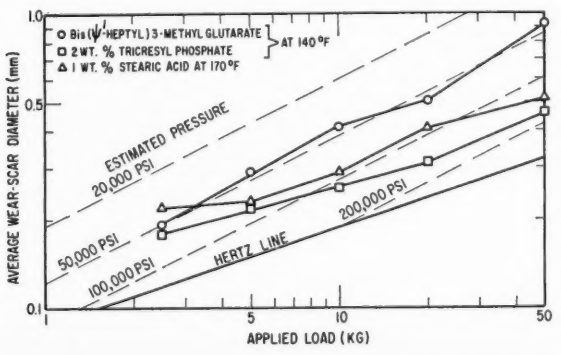

Figure 6. Effect of additives in bis(ψ'-heptyl) 3-methylglutarate on wear rate of hard steel on hard steel.

Table VII

Effect of Concentration of Tricresyl Phosphate on Antiwear Properties of Bis(ψ'-heptyl) 3-methyl glutarate for Hard Steel on Hard Steel (Av. Scar Diameters at 20 Kg. Loads)

Percent Tricresyl Phosphate (By Weight)	Average Wear Scar Diameter (mm.) of Steel Cup Balls
	140°F
None	0.52
0.05	0.44
0.14	0.31
1.0	0.33
2.0	0.31
4.0	0.32
10.0	0.31
40	0.39

The results of employing addition agents in bis(ψ'-heptyl) 3-methylglutarate are shown in Figure 6. Wear measurements with 1 percent stearic acid were made at 170 instead of 140° F. in order to keep it in solution. The effect of this acid was to decrease the rate of wear or increase the load-carrying capacity. A two-percent concentration of tricresyl phosphate was again more effective than one percent of stearic acid in decreasing wear. The effect of varying the concentration of tricresyl phosphate in bis(ψ'-heptyl) 3-methylglutarate was studied at 140°F., and the results are given in Table VII. The same low wear rates were obtained with weight concentrations as low as 0.14 percent and as high as 10 percent of tricresyl phosphate.

The results of wear measurements at 266°F. for the same compounds are given in Figure 7. At this temperature, where the wear rate of the pure fluoroester was found to be at a minimum, the addition of stearic acid caused an increase in wear at all loads except 50 kg. In contrast, the effect of tricresyl phosphate was still beneficial and the wear-scar curve at this temperature almost coincided with the 140° curve. Even at 400°F. the scar diameters were only 0.17, 0.23, 0.26, 0.34, and 0.55 mm, or nearly the same as those measured at the two lower temperatures. This should be compared to the large increase in wear which resulted when the temperature of the uncompounded fluoroester was increased from 266 to 400°F.

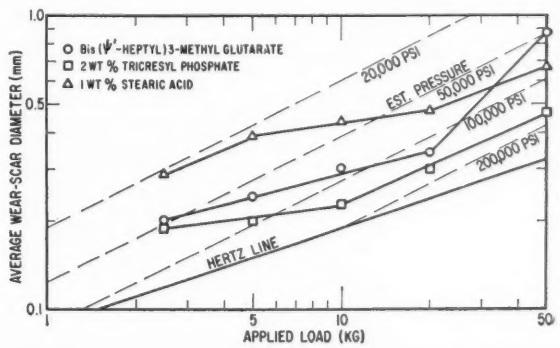

Figure 7. Effect of additives in bis (ψ'-heptyl) 3-methylglutarate on wear rate at 266° F. (data obtained for hard steel on hard steel).

Friction measurements with the four-ball machine showed that the addition of tricresyl phosphate to either diester decreased only slightly the coefficient of friction for hard steel (usually from 0.12 to 0.10). When the addition agent was stearic acid, the coefficient of friction was reduced to 0.06, even though this acid was never as effective as tricresyl phosphate in reducing wear.

Earlier work at this Laboratory had revealed that some lubricants which were satisfactory when four hard-steel balls were used, permitted extreme wear when either the spindle or cup balls were of soft steel.[8] Therefore, a limited number of experiments were conducted with soft-steel cup balls (SAE X1015) and a hard-steel spindle ball. Although, as expected, the rate of wear was higher with hard steel on soft steel than with hard steel on hard steel, it was not excessive when the lubricant was bis(ψ'-heptyl) 3-methylglutarate (Figure 8). This nonadditive fluoroester is a better boundary lubricant than the nonadditive bis(2-ethylhexyl) sebacate. Also shown in Figure 8 is the curve for a chlorinated silicone taken from a recent report.[8] Although this silicone was a vastly superior lubricant when compared with the unchlorinated silicones, it is much inferior to either type of diester. The addition of 2 percent tricresyl phosphate to the fluoroester did not decrease the amount of wear on the soft-steel cup balls. The differences between the two curves are probably within the experimental uncertainty when this grade of ball is used. The ineffectiveness of this addition agent is in marked contrast here to its beneficial effect with hard steel. To determine if there was an optimum amount of tricresyl phosphate for reducing wear for hard steel on soft steel, 0.05, 1, 2, 4, 10, and 40 weight percent of this additive were compounded with the glutarate. These solutions were studied at 140°F. using an applied load of 10 kg. The wear-scar diameters were found to vary from 0.55 to 0.65 mm. However, there was no correlation between scar diameter and percent tricresyl phosphate. It may be concluded, therefore, that in concentrations up to 40 percent, this additive in the fluoroester has no effect on the wear rate of hard steel on soft steel.

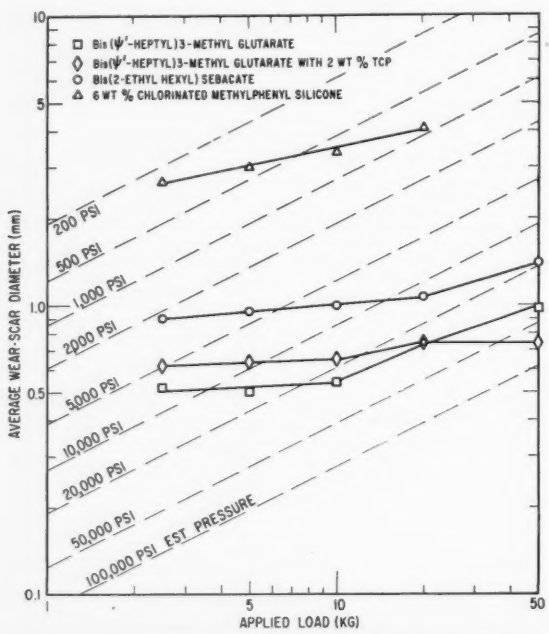

Figure 8. Comparison of wear rates at 140°F. of hard steel on soft steel for various synthetic lubricants.

The effect of adding 2 percent of tricresyl phosphate to bis(ψ'-heptyl) 3-methylglutarate on the wear rate of hard steel on bronze was also determined for the same applied loads. For these metals, the addition of tricresyl phosphate again did not significantly alter the wear results obtained with the pure fluorinated diester.

SUMMARY

The boundary-lubricating and wear-preventive properties of several partially fluorinated diesters and of bis(2-ethylhexyl) sebacate have been investigated with both the stick-slip apparatus and the four-ball wear machine at temperatures from 77° to 400°F. Friction and wear measurements were also made using typical antiwear, antioxidant, and oiliness agents compounded with each diester. These fluids were studied principally as lubricants for hard steel sliding on soft steel, hard steel, and bronze, and for bronze sliding on soft steel.

The differences in the static coefficient of friction (μ_s) among the several fluoroesters, as measured with the stick-slip apparatus, are small and may be attributed in part to differences in purity of these liquids. In addition, the values of μ_s obtained in the presence of the fluoroesters do not differ greatly from the values obtained with bis(2-ethylhexyl) sebacate for comparable conditions. Examination of photomicrographs of the wear tracks revealed that, in general, less wear had occurred when the fluoroesters were used than when the unfluorinated diester was used. Results with the four-ball machine did not reveal any significant differences in friction between bis(ψ'-heptyl) 3-methylglutarate and bis(2-ethylhexyl) sebacate, but did reveal that less wear nearly always occurred with the fluoroester and that these differences in wear were often large.

Experiments with the four-ball machine showed a small reduction in friction and, usually, a large reduction in wear as a result of compounding tricresyl phosphate with either the fluoroester or unfluorinated diester when both bearing surfaces were of hard steel. However, this addition agent in bis(ψ'-heptyl) 3-methylglutarate was not effective in reducing wear of hard steel on bronze or hard steel on soft steel.

Friction was lowered appreciably by the addition of stearic acid to either type of diester when measured with the stick-slip apparatus or with the four-ball wear machine, but this acid was not always beneficial as a wear-reducing agent.

When the temperature was increased to 400°F., both friction (measured with the stick-slip apparatus) and wear (measured with the four-ball machine) nearly always increased markedly with either type of diester. However, when bis(ψ'-heptyl) 3-methylglutarate containing tricresyl phosphate was used to lubricate hard-steel surfaces in the four-ball machine, approximately the same low wear rates were observed at 140, 266, and 400°F.

It is concluded that the uncompounded fluoroesters have boundary-lubricating properties which are as good or better than those of the uncompounded bis(2-ethylhexyl) sebacate. Because of their exceptional thermal and oxidation stability, it will not be desirable to rely upon chemical breakdown to generate antifriction and antiwear agents; hence, the use of appropriate addition agents is recom-

mended. This investigation has demonstrated that the fluoroesters respond well to the conventional "oiliness" agents as well as to tricresyl phosphate. Since stearic acid is not appreciably soluble in the fluoroesters below the approximate melting point of the acid, an "oiliness" agent that is soluble in fluoroesters over a suitable temperature range will be required.

The good hydrolytic and thermal stabilities possessed by these fluoroesters, their exceptional resistance to atmospheric oxidation at high temperatures, and good resistance to oil mist explosion hazards, together with their acceptable boundary-lubricating characteristics, and excellent response to additives, indicate that the fluoroesters will prove to be valuable "base stocks" for the formulation of improved high-temperature lubricating oils and greases.

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COMMENTARY

P. H. BOWEN, WESTINGHOUSE ELECTRIC CORP.

The authors have presented in this paper interesting data on boundary lubrication properties, thermal and oxidation stability of fluorinated esters for consideration, and additional evaluation as materials for formulating high-temperature lubricants. In their comparison of these fluorinated esters with other fluorinated compounds and the familiar sebacate, several comments are noted.

The friction characteristics of the sebacate and fluoroether fluids are of interest in the slip stick tests when the hard steel slider moved over the lubricated soft steel platen. These two materials exhibited an increasing coefficient of friction during the 10 traversals of the slider at 77° F., while the fluoroesters and the perfluorinated kerosene showed a slight decrease in friction. Similar differences in coefficient of friction were observed for repeated traverses of hard steel on brass lubricated with the ether, but not when lubricated with the sebacate. It would be desirable to determine if these particular friction values have reached a steady state for the fluorinated esters and sebacate fluids, as the number of slider traverses would be increased; or if the tests were repeated at elevated temperatures.

With regard to the wear tests, determination of the wear preventive characteristics of the methyl glutarate are of interest. Minimum wear occurs at a load of 20 kg and a temperature of 266° F. Within the limit of the test temperatures used, it would be desirable to explore the similar optimum conditions for the sebacate fluid. This information may aid in a better understanding of the film breakdown characteristic of the sebacate lubricant.

These tests show that additives can be used successfully in these fluoroesters to further improve the boundary lubricating characteristics. Since these fluids were evaluated primarily as materials for high temperature lubricants, it would be well to explore the volatility of each material.

AUTHORS' CLOSURE

The authors wish to thank Dr. Bowen for his comments and suggestions. Further research will be necessary to explain all of the experimental data reported. The use of the multiple traverse technique with the Bowden-Leben machine offers interesting and new possibilities in investigating the ability of liquids to serve as boundary lubricants for metals. As far as we are aware, in the few times in the past where this technique was used, the objective was to study the durability of either a monolayer or a multilayer film deposited on the metal. In the May 1956 issue of *Industrial and Engineering Chemistry*, we have shown that the use of the multiple traverse technique can supply illuminating information on the change in the boundary lubricating behavior of silicones caused by the substitution of chlorine on the phenyl groups. In the paper presented here, we have shown this multiple traverse technique to be useful for studying the fluorinated esters. Our main objective in this publication was to show that the fluoroesters will lubricate as well as, if not better than, the unfluorinated esters; this has resulted in a rather lengthy paper. Therefore, we have not attempted to explain all the differences in the behavior noted for the fluoroesters as compared to fluoroethers, perfluorinated kerosene, etc. However, the shape of the curves for all lubricants and for both metal combinations at 77° F. indicate that μ_s had reached a steady value by the 10th traverse. The effects of the repeated traverses were not studied at more elevated temperatures; undoubtedly it deserves further attention.

With respect to the point raised by Dr. Bowen in the third paragraph, similar high-temperature studies of the unfluorinated esters are of questionable significance because of their more extensive oxidation breakdown in the absence of the antioxidant. Of course, the addition of an antioxidant can greatly complicate the interpretation of the wear rate measurements.

Finally, volatility varies greatly among the fluoroesters reported. Undoubtedly, some of these new compounds will be limited in high-temperature applications to uses in closed systems. Appropriate data concerning the boiling points and related properties have been recently published by our Laboratory (*Ind. Eng. Chem., 48,* 445 (March 1956)). We are endeavoring to develop other fluoroesters having much higher boiling points; however, this is difficult if we are to maintain the same low pour points.

ASLE-ASME

3rd Annual Lubrication Conference

October 8-9-10, 1956 Atlantic City, New Jersey

Organization of a Plant

Lubrication Program–I

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Master Mechanic
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Editors Note: **This is the first in a series of three articles on organizing the plant lubrication program which were presented at the 10th annual meeting of ASLE in Chicago. Other papers from the panel session will be presented in future issues of *Lubrication Engineering*.**

PROGRAM REQUIREMENTS

To dwell at length on the need for a controlled lubrication program for any industrial project would seem almost elementary. Undoubtedly, it will be agreed that proper lubrication of machines, motors, spindles, bearings, and friction surfaces is extremely essential, and if properly instituted and controlled, can be a very important factor in attaining more efficient service, less down time, prolonged mechanical life, and reduced maintenance costs.

Therefore, it would seem most beneficial to discuss the requirements of a good lubrication program, and to point out some of the difficulties which may occur while trying to set up such a program.

Common Problems

Of course, problems will vary, depending upon such things as the size of the project, labor agreements, and seniority regulations. However, most problems will probably parallel those which were faced by the Continental Motors Corporation and, therefore, the balance of this article will deal with those specific problems and their solutions.

First, there is the problem of seniority ramifications. Our labor contract classifies the job of "oiler" as one in the lower classification group and consequently carries a lower rate of pay than most jobs in the plant. This means that upon acquiring a certain amount of seniority, the oilers often bid for a job of higher classification and rate. Also, in the event of a layoff, as the employees are reduced in classification, due to manpower reductions, the men remaining with the lower seniority are forced to take the job of oilers.

As a result of this constant change, it is almost impossible to train specific individuals for this job, even though the job is extremely important. Coupled with this is an additional problem, that of the various types of lubricant required and the large number of places to be lubricated on certain machines. For example, one turret lathe requires a certain type of lubricant in 12 places daily, another type in 29 places weekly, and still a third type of lubricant in 2 places semi-annually.

In another case, a certain grinder requires one type of lubricant in 22 places daily, another type in one place daily, a third type in six places weekly, a fourth type in one place weekly, a fifth type in one place weekly, and a sixth type in six places semi-annually. Multiply this condition by approximately 250 machines and it becomes quite apparent that proper lubrication of each machine requires a well-planned, foolproof and consistent program, and one which can be operated efficiently, despite the handicaps imposed by seniority rules and complexity of equipment. At Continental Motors Corporation, this problem was studied carefully, and as a result, a lubrication program was designed and instituted in the early part of 1953. This program has been highly successful and operates with a minimum amount of supervision and personnel.

Color Coding and Symbols

The program operates as follows. Each lubricant used throughout the plant is assigned a color code, or symbol of its own. These symbols are in the form of crosses, squares, triangles, and rectangles. Each symbol has its own color. For example, one type of lubricant is identified by a red cross, another by a yellow cross, another by a green cross, another by a red square, and another by a green square.

As soon as a drum of lubricant is received in the plant, the tool stores supervisor has the symbol for that lubricant painted on the top of the drum. The symbol is painted in the designated color and about six inches in size. Hereafter, this lubricant is identified by this symbol rather than its specific name.

A number of two gallon containers were designed and built to fit a special hand cart used by the oiler. These containers are also identified by the color code symbols, each container with a different symbol. The containers are filled by the oiler from the main drums, which are on a special drum rack. The oiler need not know the name or the brand of lubricant he is using. He simply fills his container with the red square symbol from the drum with the corresponding symbol. Each container is filled from the drum with matching colored symbols. The oiler then proceeds to make the rounds of the machines assigned to him.

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Assignment Cards and Check Sheets

At the outset of this program, each point of lubrication on each machine was painted with the assigned color symbol for the lubricant required. At the same time, a card was designed showing each lubricant used throughout the plant. This is a standard form and is printed in large quantities as standard form blanks. These cards are then filled in with the machine name, number, and location. Small rubber stamps have been provided to correspond with each symbol used. Red, green, and yellow ink pads are used to stamp the required symbols on the cards for the individual machines. The symbols are stamped with the proper colors and under the proper columns of daily, semi-weekly, weekly, or semi-annually. (*See Table I.*) The filled-in cards are then placed in transparent plastic envelopes and are fastened to the machine corresponding with the title on the card. A set of duplicate cards is kept in the Master Mechanic's Department as a master set. A daily check sheet was also designed and printed in large quantities (*Table II.*) These sheets are kept by the maintenance supervisor and are assigned to the oilers each day. The oiler clips the check sheet to his clip board and proceeds to make his rounds.

He consults the check sheet, which tells him the machines to which he has been assigned, and which elements he is to take care of, such as semi-weekly, weekly, or semi-annually. Daily elements, of course, are self-explanatory. Before the oiler starts on an assigned machine, he first consults the card in the transparent envelope fastened to the machine. This card is his guide to the type of lubricant he is to use as well as the number of places in which to use it. For example, in the case of a certain tapping machine, the card tells the oiler that the element painted with the yellow square on the machine is to be lubricated on that day, inasmuch as the yellow square appears on that card under the daily column. The typed numeral *"1"* next to the yellow square tells him that there is just one such symbol painted on the machine. He then picks up the oiling can from his cart with the square yellow symbol and proceeds to oil the one element on the machine. He then reads the next symbol on the card under the daily column, which, in the case of this machine, is a green cross with the numeral *"3"*. He picks out the oiling can with the green cross symbol and proceeds to find and oil the three elements on the machine identified by the same symbols. This completes the daily requirement on this particular machine. The oiler then consults his clip board check sheet to see if the weekly, semi-weekly, or semi-annually elements are to be lubricated on that day. Upon completing that machine, the oiler checks off all the elements on his clip board check sheet and initials it.

The fact that the small numerals appear on the lubrication cards next to each symbol, gives the oiler the assurance that he has oiled every point. This takes the element of guess away from him and insures more uniform and consistent lubrication throughout the plant.

Program Advantages

As a matter of fact, under this system of controlled lubrication, the constant change in personnel is an advantage rather than a hindrance. If it were possible to use the same men every day for any extended period, they would probably soon come to the belief that they were capable of oiling all elements without the help of the cards and consequently make many "misses." On the other hand, a newer man is entirely dependent upon the record cards and thus is forced to follow them precisely.

After completing his rounds for the day, the oiler signs his clip board check sheet and turns it in to the maintenance supervisor. In signing this sheet, the oiler is attesting that he has lubricated every point properly on each machine assigned to him for that day. These check sheets are kept on file for consulting purposes, should that be necessary.

Preventive Maintenance

As a physical check on the consistency of this program, the preventive maintenance plan, which is also in operation at Continental Motors, provides for a continual daily check on each machine for the detection and prevention of breakdowns. The daily check is made by a thoroughly experienced machine repair man assigned full time to this function alone. In the course of this plan, the lubrication elements are checked continually for freedom from clogging and effectiveness of operation. This preventive plan has proven that the lubrication program is very effective and dependable and has definitely added to the life of machines and tools in operation.

Furthermore, the records prove that since the institution of the lubrication program, the cost of lubricants have taken a definite drop and substantial savings have been realized. All in all, the program has been well accepted by the production and maintenance supervising

TABLE I
LUBRICATION ASSIGNMENT CARD

Dept. No. 118	Machine Description No. 12 Tapper	Machine Line A	Machine Line No. 1	C.M.C. Machine Tag Number

Specification of Lubricant		Lubrication Symbols and Points on the Machine				Notes
Grade*	Type	Daily	Weekly	Semi-Weekly	Semi-Annually	
—Oil	600-W		1			
—Oil	Light					
—Oil	Heavy Med.	1				
———	Ex. Heavy	3				
———	Heavy Med.					
———	No. 2					
———	E					
—Oil	No. 1					
———	No. 1		4		1 Motor	

KEY: blue, yellow, red

In keeping with editorial policy, grades, listed by trade name have been deleted.

group, and has removed numerous problems of a controversial and troublesome nature.

It is hoped that this article provides a clear outline of our procedure and that it may in some way be helpful and beneficial to those contemplating a lubrication program for their own plant.

Mr. A. Bolden studied engineering at the University of Detroit. After completing his apprenticeship in tool engineering with National Twist Drill & Tool and Packard Motor Car, he worked for the Ford Motor Co. as a tool engineer, and later for the Union Twist Drill & Tool Co. Mr. Bolden joined the Continental Motors Corp. in 1951. In his present capacity as Master Mechanic he is responsible for costs, design and development of tooling, shop equipment, maintenance and plant engineering in various departments of Continental Motors.

TABLE II
MACHINE LUBRICATION CHECK SHEET*

Machine Tag. No.	Line	Mach. No.	Weekly	Chk	Mo.	Chk	Semi-Annual	Chk
11139	A	1	W		—	—	—	—
997	A	3	—	—	—	—	SA	
9847	A	5	—	—	—	—	SA	
162	A	7	—	—	—	—	SA	
A-151-2	A	9	—	—	—	—	SA	
10974-B	A	11	—	—	—	—	SA	
10976-B	A	13	—	—	—	—	SA	
9522-B	A	15	W		—	—	SA	
9736-C	A	23	—	—	M		SA	
9525-B	A	25	W		M		SA	
10648-A	B	1	W		—	—	SA	
11234-A	B	3	—	—	—	—	SA	
10591	B	5	—	—	—	—	SA	
9727-C	B	7	W		—	—	SA	
10730	C	1	W		—	—	SA	
253	C	10	—	—	—	—	SA	
11260-A	D	11	W		—	—	SA	
9720-C	D	17	W		—	—	—	—

Clock No. ——————Shift——————Date——————Dept. 118

**Machines requiring weekly, monthly, or semi-annual lubrication*

QUESTIONS AND ANSWERS

Q. Isn't semi-weekly frequency periods cutting a rather fine point?

A. It may be cutting a fine point, but we did not determine that ourselves. As a new machine is received in the plant we follow strictly the recommendations of the machine manufacturer. He tells us which elements are to be lubricated, and how often. We do not question the recommendation.

Q. Doesn't your paper work and record keeping impose a great expense and burden on your company?

A. I cannot tell you the exact cost at the present time, but I do know it was checked into by our comptroller, who watches pennies very carefully, and he has pronounced it very economical.

Q. You mentioned your lubricant costs are now appreciably less. Upon what unit of measurement do you base your costs — cents per piece, dollars per hour, or dollars per machine per month?

A. Before instituting our program, we had 32 different types of lubricants in the plant. We have now settled down to about nine types that cover our entire operation. The frequency of purchase, and the quantity of purchase, compared to the frequency and quantity previous to the installation of our system has established that there has been a 30 percent savings in lubricant costs.

Q. Do you schedule oil changes through the maintenance scheduling department?

A. Yes, definitely. We schedule it from our card records by the maintenance supervisor. He assigns the actual work of oil changing and lubricating to the oilers. We have five such people doing about sixty machines apiece a day. It is definitely done through the maintenance department under the maintenance supervisor.

Q. Who opens and cleans your larger reservoirs?

A. The opening and draining of the reservoirs is done by the chip and coolant men; cleaning and flushing out, the removing of screens, and the washing and replacing of screens is done by a machine repair man assigned to that function alone.

Q. Does that apply to big speed reducers?

A. Definitely. We have only three speed reducers in our plant and these are located on tumbling devices.

Q. You are running tests daily on lubricants. If only on a "proof of the pudding" basis, shouldn't this experience be evaluated as a source for additional savings on maintenance?

A. We did not run daily tests as such. At the time we started our studies it was merely a process of elimination. We had the 32 types of lubricants. When it came to the point of choosing which to use permanently, we could have chosen five or ten that were equally good. The tests that we ran were not to find out which would last longest. I concede that this is what should have been done, but time did not permit it. We merely ran tests to see if the lubricants were equal to each other within a certain degree, then settled on one company and are buying our lubricants from that company. In choosing this particular company we excluded many that were just as good. There was no real basis for excluding the others except that we had to start somewhere, so we picked one good brand and started there.

Q. How does your system compensate for variations in hours of operation on a particular machine?

A. We have about 300 machines in our plant, doing about 3,750 operations. We are constantly changing jobs, and almost all of the machines are in constant use. We would have a problem if a machine were used forty hours of the month and then sat idle for the rest of the time. But they are being used, because of the variation in operations, and we have to use every one almost every hour on both shifts. Therefore, machine use is quite constant, fortunately for us, otherwise we would have a problem on our hands and would have to refine the program further.

Q. With your rather heavy turnover in your crew of oiler men how do you control application of the lubricant from the standpoint of over- or under-lubrication?

A. That has always been a problem. I mentioned the maintenance program which follows up the work of the oilers. The maintenance man assigned to this function has the highest seniority in his classification. His judgment is very good and has been very beneficial in the past. As he checks every machine daily he will warn the supervisor when he finds that there has been over- or under-lubrication. The supervisor will then take the oiler back to that machine and instruct him. This has not happened too often. It has happened through over-greasing of motors, but a few words of instruction have straightened out those instances. I feel that we have been fortunate in this respect and that our system has worked out very well.

Q. How do you balance the oiler's workload during the period when he is carrying out semi-annual and annual servicing as well as his daily routine?

A. Every machine is lubricated on some elements every day. Therefore, every machine is approached. The supervisor may assign four, five or six lines (line A, line B, line C, line D, and so on) to one oiler. The elements requiring weekly, semi-weekly, and semi-annual lubrication are assigned to him. The assignment card has a place which gives the line and the machine number. When the oiler gets to a machine he looks at the assignment card, which may tell him that this is the day for the weekly elements. He consults the card fastened to the machine, proceeds to count the weekly elements and oil them. As he goes up and down the line every day, the assignment card tells him which machines are due for weekly, semi-weekly, and semi-annual elements.

Q. If two or more elements on one machine require the same lubricant but at different times, how does the oiler know the difference, since both will carry the same symbol?

A. That is a very good question. Fortunately, this situation has not occurred. If the oiler found two elements on the machine

Third Annual

ASME

ASLE

October 8, 9, 10, 1956

Lubrication Conference

Chalfonte-Haddon Hall
Atlantic City, New Jersey

TENTATIVE PROGRAM

Monday, October 8, 1956

Session I—10:00 A.M.—Viking Room

Bearing and Lubricant Problems in Nuclear Power Plants—Part I

E. E. Bisson, *Lewis Flight Propulsion Lab., NACA, Cleveland, Ohio*, Vice Chairman

REVIEW OF LUBRICATION PROBLEMS IN NUCLEAR POWER PLANTS
R. F. Hausman and E. R. Booser,
General Electric Co., Schenectady, N. Y.
☐ *ASLE Preprint No. 56LC-1*

GENERAL RADIATION DAMAGE ASPECTS OF LUBRICANT AND BEARING TYPE MATERIALS
V. P. Calkin, General Electric Co., Evandale, Ohio
☐ *ASLE Preprint No. 56LC-2*

Session II—2:00 P.M.—Viking Room

Bearing and Lubricant Problems in Nuclear Power Plants—Part II

E. E. Bisson, Vice Chairman

SLIDER BEARING OPERATION IN SODIUM OR SODIUM-POTASSIUM ALLOYS
D. B. Vail, General Electric Co., Schenectady, N. Y.
☐ *ASME Paper No.*

USE OF ROLLING CONTACT BEARINGS IN LOW VISCOSITY LIQUID METAL LUBRICANTS
W. Markert, Jr., and K. Mildred Ferusson,
Babcock-Wilcox Co., New York, N. Y.
☐ *ASLE Preprint No. 56LC-3*

RADIATION RESISTANT GREASES
J. G. Carroll, R. O. Bolt, and B. W. Hotten,
California Research Corp., Richmond, Calif.
☐ *ASLE Preprint No. 56LC-4*

EFFECTS OF NUCLEAR RADIATION ON LUBRICANTS
J. A. King and W. L. R. Rice,
WADC, USAF, Dayton, Ohio
☐ *ASLE Preprint No. 56LC-5*

Tuesday, October 9, 1956

Session III—9:00 A.M.—Viking Room

Friction & Boundary Lubrication—Part I

E. Rabinowicz, *Massachusetts Institute of Technology*, Vice Chairman

A FUNDAMENTAL STUDY OF SYNTHETIC SAPPHIRE AS A BEARING MATERIAL
L. R. Coffin, Jr., General Electric Co.,
Schenectady, N. Y.
☐ *ASLE Preprint No. 56LC-6*

STATISTICAL ANALYSIS OF A WEAR PROCESS
B. G. Rightmire, Massachusetts Institute
of Technology, Cambridge, Mass.
☐ *ASME Paper No.*

ON SLIDING FRICTION BETWEEN UNLUBRICATED METALLIC SURFACES
F. F. Ling and E. Saible, Carnegie Institute of
Technology, Pittsburgh, Pa.
☐ *ASLE Preprint No. 56LC-7*

← *Remove for posting on your bulletin board.*

Session IV—2:00 P.M.—Viking Room

Friction & Boundary Lubrication—Part II

A. C. West, *California Research Corp., Richmond, Calif.*, Vice Chairman

SOLID FILM LUBRICANTS — FACTORS INFLUENCING THEIR MECHANISM OF FRICTION AND WEAR
R. E. Crump, Electrofilm Corp., North Hollywood, Calif.
☐ *ASLE Preprint No. 56LC-8*

INFLUENCE OF TEMPERATURE ON BOUNDARY LUBRICATION
C. W. Cowley, D. J. Ultee, and C. W. West, Linde Air Products, New York, N. Y.
☐ *ASLE Preprint No. 56LC-18*

FRETTING OF HARDENED STEEL IN OIL
J. R. McDowell, Research Laboratories, Westinghouse Electric Co., Pittsburgh, Pa.
☐ *ASLE Preprint No. 56LC-9*

PbO AND OTHER METAL OXIDES AS SOLID LUBRICANTS TO 1000°F
M. B. Peterson, General Engineering Laboratories, General Electric Co., and R. L. Johnson, NACA, Cleveland, Ohio
☐ *ASLE Preprint No. 56-10*

Wednesday, October 10, 1956

Session V—9:00 A.M.—Viking Room

Hydrodynamic Lubrication—A Reporter Session

F. W. Ocvirk, *Cornell University*, Vice Chairman

EXPERIMENTS ON GAS LUBRICATED JOURNAL BEARINGS
M. Wildmann, Autonetics Div., North American Aviation, Los Angeles, Calif.
☐ *ASME Paper No.*

TESTING DYNAMICALLY LOADED BEARINGS—I: A SHORT HISTORY OF BEARING TEST MACHINES
M. D. Hersey and R. B. Snapp, Naval Engineering Experiment Station, Annapolis, Md.
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L. F. Kreisle
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UNIVERSAL BEARING TESTER
R. J. S. Pigott and B. R. Walsh
☐ *ASME Paper No.*

HEAT TRANSFER EFFECTS IN HYDROSTATIC THRUST BEARINGS
W. F. Hughes and J. F. Osterle, Carnegie Institute of Technology, Pittsburgh, Pa.
☐ *ASME Paper No.*

PROPERTIES OF MISALIGNED JOURNAL BEARINGS
G. B. Du Bois, F. W. Ocvirk, and R. L. Wehe, Cornell University, Ithaca, N. Y.
☐ *ASME Paper No.*

A SOLUTION FOR THE FINITE JOURNAL BEARING AND ITS APPLICATION TO ANALYSIS AND DESIGN—II
A. A. Raimondi and J. Boyd, Research Lab., Westinghouse Electric Co., Pittsburgh, Pa.
☐ *ASLE Preprint No. 56LC-12*

INVESTIGATION OF "MELT LUBRICATION"
B. Sternlicht and H. Apkarian, General Electric Co., Schenectady, N. Y.
☐ *ASLE Preprint No. 56LC-13*

Session VI—2:00 P.M.—Viking Room

Lubricants

H. A. Hartung, *Atlantic Refining Co., Philadelphia, Pa.*, Vice Chairman

YIELD STRESS AS A FACTOR IN THE PERFORMANCE OF GREASES
D. Evans, J. F. Hutton, and J. B. Matthews
☐ *ASLE Preprint No. 56LC-14*

GREASE LUBRICATION OF HI-SPEED ANTRIFRICTION BEARINGS
J. B. Accinelli and C. R. Greene, Shell Development Co., Emeryville, Calif.
☐ *ASLE Preprint No. 56LC-15*

SPECIFIC HEAT AT LOW TEMPERATURES AND HEAT OF FUSION OF AIRCRAFT ENGINE LUBRICANTS AT LOW TEMPERATURES
V. E. Schrock and R. E. Gott, University of California, Berkeley, Calif.
☐ *ASLE Preprint No. 56LC-16*

THERMAL CONDUCTIVITY AND THERMAL DIFFUSIVITY OF AIRCRAFT ENGINE LUBRICANTS AT LOW TEMPERATURES
V. E. Schrock and E. S. Starkman, University of California, Berkeley, Calif.
☐ *ASLE Preprint No. 56LC-17*

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Session IV—2:00 P.M.—Viking Room

Friction & Boundary Lubrication—Part II

A. C. West, *California Research Corp., Richmond, Calif.*, Vice Chairman

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3rd Annual

ASME-ASLE Lubrication Conference

The jointly sponsored annual Lubrication Conference of the ASME-ASLE has achieved an outstanding reputation for bringing together leading scientists in the field of Lubrication to discuss and present information on the latest theories, equipment, and techniques.

Featured on the outstanding program for this year are the two sessions treating the problems on bearings and lubricants in the presence of nuclear radiation. Papers will cover radiation damage to the lubricant and to materials used for bearings; liquid metal lubricants used for rolling contact bearings; problems associated with nuclear power plants; lubricants resistant to the effects of radiation; and slider bearing operation in light metal alloys.

Another feature of this year's conference will be the incorporation of the reporter-type session as is employed by the English Societies to permit the most comprehensive exchange of technical information and comments within a limited amount of time. This type of session presupposes the audience has read and digested the preprint of the author's work. Only a brief synopsis of each paper is read and a maximum amount of time is allocated to the discussion of the work by the audience. Twelve papers are tentatively scheduled for this session.

This year's conference headquarters will be the Chalfonte-Haddon Hall on the boardwalk in Atlantic City, New Jersey. Complete details will be found in the accompanying program information.

having the same symbol he wouldn't know which is weekly and which semi-annually. We considered this possibility at the time we set up the system, but found that this did not occur. If it did, we would have had to make some sort of provision, perhaps by the addition of a prefix next to the symbol. I think it could be solved if it ever came up.

Q. With your program organized as it is, pretty completely, why do you continue to keep your oilers at such a low menial level as you stated? Why are you going to continue to have them rated as low as that?

A. This was a necessary evil that grew out of the rapid growth of the Detroit Division. As I have said, production ran far ahead of our services, and by the time we had our services organized it just so happened that the lower rated men were classified as oilers, and, union-wise, it was hard to change. I believe that the oiler should be of a high classification and a good rate of pay. It is a very important job. However, in attempting to try to get a higher type of labor as oilers, we have had them refuse the job. A machine repair man does not want to go on to the job of oiler alone. He feels that his job is higher skilled and better. And, thus far, in asking these men, they have all refused. We have no choice, by union contract, but to leave it just where it is, although as I say, it certainly should be a high classification. It is an important function.

Q. Do you favor centralized lubrication application on machines not so equipped when they are originally purchased?

A. We have added centralized lubrication elements to our machines in many cases. Of course, there are a lot of machines that do come so equipped and this is an advantage.

Q. Lubrication of grease-lubricated sealed bearings has been the cause of many bearing failures. How is this controlled by your plant?

A. Well, again, through our preventive maintenance system. We do a great deal of close tolerance work in oil pumps, boring gear cavities. We have set up a system whereby if our preventive maintenance man, in his regular rounds, detects any defect in a spindle, or if the machine operator detects a defect, or if the surface finish of the work is not right and the operator cannot control it by changing the cutting tool, he will call his foreman and the preventive maintenance man to examine that machine. If there is any indication whatsoever that it is the bearings that are causing the trouble, that spindle comes off. We have a large bank of replaceable spindles in our storeroom, and we immediately change that spindle, and send the one in question to the manufacturer of the machine. They have testing facilities and are able to test the bearings for us and advise us accordingly. If there is a failure occurring in the bearing, we issue a purchase order to the manufacturer to correct it.

Personals

B. T. Harding, National Chairman of the ASLE Membership & Admissions Committee, has been promoted to Chief Engineer of the Industrial Department of Midwest Oil Co., Minneapolis, Minn.

Quaker State Oil Refining Corp., Buffalo, N. Y., has announced the appointment of **F. O. Koontz** as Executive Vice-President; **C. W. Georgi** (ASLE Buffalo Section), Director of Research, was elected a Vice-President.

P. M. Ruedrich (ASLE N. California Section), Griffin Chemical Co., Richmond, Calif., has been elected Assistant Secretary of the San Francisco Advisory Committee for the Engineering Societies Personnel Service, Inc.

A. J. Zino, Jr. (ASLE New York Section), has been appointed Vice-President in Charge of Sales, for Dixon Sintaloy, Inc., Stamford, Conn., a subsidiary of the Joseph Dixon Crucible Co.

Socony Mobil Oil Co., Inc. has announced the appointment of **E. S. Reynolds** (ASLE New York Section) as Senior Engineering Representative, Industrial Division, with headquarters in New York City; and the appointment of **D. D. Schnack** as Engine Builders Representative in western Pennsylvania and western New York state, with headquarters at McKees Rocks, Pa.

B. T. Harding

E. S. Reynolds

C. L. Bierley (ASLE Youngstown Section), formerly with Swan-Finch Oil Corp., is now District Manager for Magie Bros. Oil Co., with headquarters at Columbiana, Ohio.

R. O. Braendle (ASLE Philadelphia Section) has been appointed Assistant to the Manager of Additives Sales, Petroleum Chemicals Div., E. I. du Pont de Nemours & Co., Inc., with headquarters in Wilmington, Dela.

Lincoln Engineering Co., St. Louis, Mo., has merged with The McNeil Machine & Engineering Co. (of Akron, Ohio), under the new name of **Lincoln Engineering Co., Division of The McNeil Machine & Engineering Co.** The former President of Lincoln, **A. P. Fox,** was elected to the McNeil Board of Directors, and as Vice-President in Charge of the new Lincoln division.

T. W. Miller has been appointed Executive Secretary of the National Lubricating Grease Institute, Kansas City, Mo.

R. K. Smith, formerly associated with Houdry Process Corp., has been appointed Manager of Research for E. F. Houghton & Co., Philadelphia, Pa.

3rd
ASLE-ASME
Lubrication Conference
October 8-9-10

High-Temperature Bearing Operation in the Absence of Liquid Lubricants

S. S. Sorem & A. G. Cattaneo
Shell Development Company
Emeryville 8, California

Attempts were made to operate single-row, deep-groove, steel-cage ball bearings at 10,000 rpm and 600° F. with a radial load of about 30 lb in the absence of any liquid lubricant. Examination of these bearings after short periods of operation indicated that the abrasive effect of metal oxides formed at elevated temperatures played a major role in their destruction. The removal of oxygen from the environment of the bearing eliminated most of the abrasive wear and permitted a substantial extension of bearing life. Experimentally, blanketing the running bearing with an inert gas effectively reduced oxide formation, but the most attractive solution to this problem appeared to be the use of a reducing atmosphere of air and hydrocarbon vapor. The addition of sufficient jet-engine fuel (JP-4) to the bearing housing to maintain an air-fuel ratio in the range of 7 to 10 in the bearing surrounding atmosphere was used in much of the subsequent work. Having minimized the contribution of oxidation to the failure mechanisms encountered with dry-running bearings, scuffing, particularly between the rolling elements and their cage, appeared as the next most destructive mechanism. For the prevention of scuffing, the application of conventional extreme-pressure films or boundary lubrication agents by the use of vapor phase additives or by bearing pretreatment has been investigated. Bearings pretreated with sulphur have subsequently been operated with a reducing vapor blanket up to 60 hr. at 10,000 rpm and 600° F. without appreciable damage to the rolling and sliding surfaces.

INTRODUCTION

Present-day liquid lubricants, used in high-speed antifriction bearings, all have maximum temperature limits beyond which their performance characteristics begin to deteriorate rapidly by processes such as evaporation, thermal decomposition, and oxidation. Although much research effort is being devoted to the raising of these temperature limits both by improvement of the liquids and by alteration of the environmental conditions which influence their degradation processes, engineering applications exist which demand bearing operation at temperatures considerably in excess of the limits allowed by any present or immediately foreseeable liquid lubricant.

It seemed desirable, therefore, to study the role of the lubricant in high-temperature antifriction bearings, in order to clarify its purpose and to evaluate the possibility of accomplishing the same purposes by means which are not subject to high-temperature limitations as liquid lubricants are.

This report discusses the mechanisms of failures which were observed in attempts to operate 206-size ball bearings at a speed of 10,000 rpm and temperatures up to 600° F. without lubrication. By control of the environmental conditions of the bearing, it has been found that certain of these failure mechanisms can be minimized. Thus, it has been possible to extend the operating life of dry bearings from a matter of seconds to several hours.

Contributed by the American Society of Lubrication Engineers through the Lubrication Activity of The American Society of Mechanical Engineers for presentation at the Second Annual ASME-ASLE Lubrication Conference, Indianapolis, Indiana, October 10-12, 1955.

TEST EQUIPMENT

The test equipment on which the dry bearing experiments have been conducted is shown in Figures 1 and 2. Referring to Figure 2, the bearing spindle is mounted on a taper on the drive shaft in such a manner that the fit between the spindle and bearing inner race may be adjusted by variation of the tension on the spindle-retaining screw. Similarly, the bearing outer race housing is mounted in the outer housing by a taper, allowing some adjustment of the outer race fit by variation of tension on four retaining screws (not shown). The entire bearing housing is essentially a free-floating unit to permit self-alignment. Its weight is carried by the bearing and it is restrained from rotating by springs which also may be used to apply additional radial load. Stops prevent the housing from rotating more than a few degrees in case of jamming of the bearing.

For dry experiments, the normal lubricant drain was closed and forced ventilation was supplied by continuous introduction of a metered quantity of the desired atmosphere through the lubricant supply jet. Excess blanketing gas escaped through the clearance space between the drive shaft and housing. Test temperatures were measured by a thermocouple pressed against the outer bearing race through the well shown. Elevated temperatures were maintained by eight cartridge heaters in the outer housing. These were supplied from an adjustable voltage source.

The bearings used for most of the test work were single-row deep-groove size 206 ball bearings. Previous experience with liquid-lubricated bearings on this 10,000-

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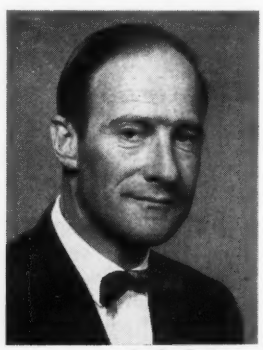

A. G. Cattaneo

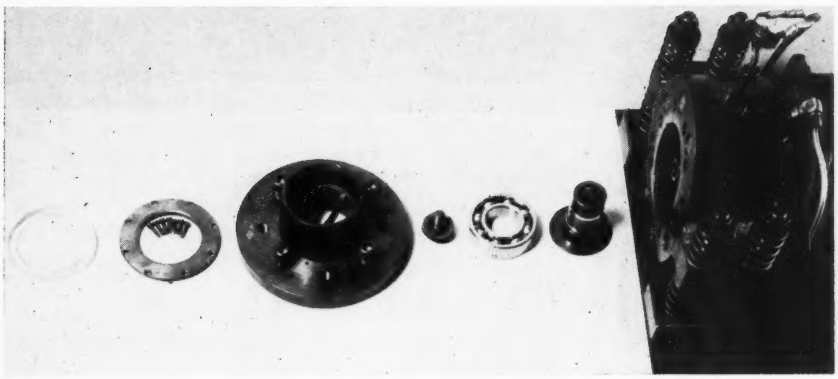

Figure 1. High-speed bearing test unit.

rpm spindle had indicated that a concentric cage was vital to obtain satisfactory high-speed operation. The particular design of bearing selected for this work had a ball-riding pressed-steel cage with a large ball-pocket contact area which minimized the tendency towards eccentric cage operation. Even so, it was necessary to inspect every bearing during initial operation and discard any which displayed visible cage eccentricity or wobble to obtain consistent results.

EXPERIMENTAL

The initial attempt at dry-bearing operation was conducted at room temperature. A new, cleaned bearing (washed in isopentane) failed after a few seconds. The addition of two drops of jet-engine oil (1010) prior to starting resulted in a bearing life of around 45 sec. Dipping the bearing in oil prior to starting gave completely satisfactory operation for over 20 min. even though most of the oil was thrown off during the first few seconds of operation. Although there is nothing startling about the foregoing observations, they illustrate something which was not learned until much later. The surfaces of a new bearing must be modified by a break-in with liquid lubrication before any operation in the dry condition can be accomplished consistently.

Once the break-in lesson had been learned, the following test procedure was set up: The cleaned bearing was installed and prelubricated with six drops of polyisobutylene, a synthetic lubricant which decomposes to substantially 100 per cent volatile compounds at about 400° F. The spindle was started and run at ambient temperature for 20 min. Heat was then applied, and the temperature increased at a rate of about 5° F. per min. until 600° F. was reached. Operation was continued at 600° F. until bearing failure occurred, or until a total time of 10 hr. had elapsed.

Using these procedures, operations in an atmosphere of air or commercial dry nitrogen (1 per cent oxygen content) gave bearing failures in 2 or 3 hr. Extreme abrasive wear was evident. The wear products contained oxides and finely divided metal. Substitution of carbon dioxide as the blanketing gas usually permitted operation for the full 10-hr. cycle. However, even with a carbon-dioxide blanket, oxidation of the bearing components became evident as the temperature approached 600° F. In the case of runs continued to 10 hr., the coating of oxide was heavy enough to start flaking off, and abrasion was beginning to appear. It seemed that a reducing atmosphere would be the desirable environment.

In the first attempt to provide the bearing with a reducing atmosphere, a mixture of CO_2 and hydrocarbon vapor (JP-4 jet-engine fuel vaporized in the CO_2 line) was used to blanket the bearing. Evidence of bearing oxidation virtually disappeared, but a considerable amount of soot accumulated in the bearing and appeared to have been a cause of wear. A run using a mixture of commercial dry nitrogen and hydrocarbon vapor as the blanketing gas gave similar results.

Blanketing the bearing with an air-hydrocarbon mixture with sufficient oxygen to oxidize most of the carbon to CO virtually eliminated soot. Several 10-hr. runs were completed using a blanketing gas having air-to-fuel ratios between about 7 and 10. Some soot formation occurred when the air-to-fuel ratio was reduced to 5. Bearing oxidation and excessive abrasion appeared as the air-to-fuel ratio was increased to be on the lean side of the stoichiometric ratio.

When using JP-4 as the hydrocarbon component of the blanketing gas, some liquid hydrocarbon was introduced to the bearing housing at temperatures below the distillation end point of the fuel (about 400° F.). These heavy ends of the JP-4 fuel were found to be suitable for bearing break-in lubrication during the low-temperature portion of the cycle. Hence, it was possible to eliminate the prelubrication with polyisobutylene in the procedure just described.

Once the oxidation-abrasion mechanism had been taken care of by use of the reducing vapor blanket, scuffing appeared as the next destructive mechanism in the hot, dry-running bearings. Scuffing occurred primarily between the rolling elements and their cages where the sliding velocity is maximum. The latter observation has been

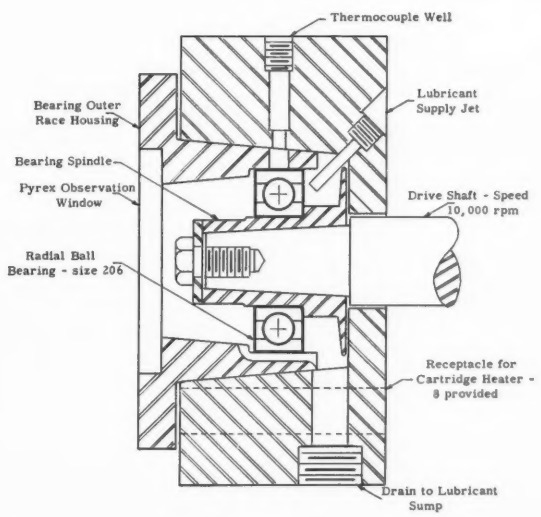
Thermocouple Well
Lubricant Supply Jet
Bearing Outer Race Housing
Bearing Spindle
Pyrex Observation Window
Drive Shaft - Speed 10,000 rpm
Radial Ball Bearing - size 206
Receptacle for Cartridge Heater - 8 provided
Drain to Lubricant Sump

Figure 2. High-speed bearing assembly.

checked with bronze-caged roller bearings as well as with the steel-cage ball bearings used in most of this work.

In an effort to prevent scuffing in dry-running bearings, the possibilities of film-forming substances such as are used in conventional extreme-pressure lubricants have been investigated. The first attempt involved the introduction of compounds containing extreme-pressure elements such as sulphur or phosphorous along with the reducing vapor blanket. When the compounds selected were volatile at the test temperature, a definite reduction in scuffing was observed. Generally, a compromise was necessary in this method of application, since the quantity of additive which would give protection against scuffing during the first few revolutions of the bearing approached the maximum quantity tolerable from the standpoint of corrosion in a run of long duration. It appeared that the most effective application of an extreme-pressure agent would be made in two stages: first, a concentrated application which would form an extreme-pressure film before the onset of scuffing, followed by a dilute application just sufficient to maintain the film.

Work on the two-stage application of the extreme-pressure agent led to the idea of a pretreated bearing. One of the simplest methods found for the initial application of an extreme-pressure film involved the actual operation of the bearing at a moderate temperature in an oil containing a conventional EP additive. Using bearings so pretreated, it was possible to obtain successful operation in dry state at 600° F. with very small quantities of active extreme-pressure element in the blanket gas to maintain the EP film. In fact, the natural sulphur content of the JP-4 used (about 0.18 per cent) was sufficient to maintain the film on a sulphur pretreated bearing.

The most successful experiment thus far has involved the use of bearings pretreated by operation in a sulphurized mineral oil (viscosity 150 SSU at 100° F., 1 per cent S) at 400° F. for 4 hr., followed by a rinse in petroleum solvent to remove any heavy oil which would carbonize at high temperatures. Subsequent operation of these bearings at 600° F. under an air-JP-4 vapor blanket (A/F=8) was possible for periods up to 60 hr. without evidence of any impending bearing failure due to either abrasion or scuffing. To progress much beyond this point will require better bearings than the ones used thus far. These bearings have not been stabilized to prevent growth of the component parts at temperatures as high as 600° F. Hence, after 40 hr. or so at this temperature, they become very tight, as though they had been assembled with a high preload.

CONCLUSION

Ball and roller bearings have been operated successfully at temperature beyond the limits imposed by conventional liquid lubricants used in the presence of air. It is believed that the procedures evolved can, with further work, be put to practical use. The following conclusions have been verified on size 206 ball (and some roller) bearings operating at 10,000 rpm and 600° F. with a light radial load:

1. When ball bearings are operated dry at high temperatures, metal oxidation and oxide-induced abrasion are the major causes of bearing wear.

2. A blanket of reducing atmosphere will eliminate bearing oxidation and minimize abrasion. A mixture of air and hydrocarbon vapor provides a suitable reducing atmosphere.

3. In the absence of bearing oxidation and oxidation-induced abrasion, cage scuffing becomes the limiting factor in the life of dry-running bearings.

4. Conventional extreme-pressure elements such as sulphur can increase the scuffing resistance of dry-running bearings. These may be applied by bearing pretreatment, or as a volatile compound in the reducing-atmosphere blanket surrounding the operating bearing. It is preferable to use a combination of pretreatment and operation with a small concentration of the extreme-pressure element in the reducing atmosphere.

COMMENTARY

E. E. BISSON
NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

This is an extremely interesting study and approach to the problem of high-temperature bearing lubrication. There is fairly good agreement between Shell and NACA results since *both* show very strongly that a rich mixture is required for good bearing performance. In fact, Shell results show that good performance requires air to fuel ratios from 7 to 10 (equivalent fuel to oxygen ratios — 0.7 to 0.5, approximately). In confirmation, NACA results show good performance obtained at oil to oxygen ratios slightly greater than 0.6.

Shell results (as well as earlier GE research by Booser and Wilcock) also emphasize a point we, at NACA, have been making for some time. That is, since the rolling contact bearing requires so little lubrication for *actual* lubrication, let's get a bearing material which can operate at higher temperatures and forget about cooling the bearing. Rather, let's just worry about its lubrication. As you know, NACA has been studying the problem of lubrication at high temperature by use of: (1) Solids (graphite and MoS_2); (2) Liquids, with drop lubrication (such as described by Nemeth and Anderson for grade 1010 lubricant); and (3) Gases (such as that discussed by Murray, Johnson, and Swikert).

As one last point, have the authors made any check of their results using tool steel bearings which are dimensionally stable at 600° F.?

AUTHORS' CLOSURE

The need for bearings operating at very high temperatures is becoming more and more urgent, and it is most desirable that all possible avenues toward a solution of the problem be explored. We are well aware of the work which is being carried out by Mr. E. E. Bisson and his associates at the Lewis Laboratory of the NACA, and we hope that they will carry it on until we know the area of usefulness and limitations of each method of operation.

When our work was done, no tool steel bearings, dimensionally stable at 600° F., were obtainable. However, the work will be carried on as new bearing metals and designs become available.

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A Study of Combustion Resistant Hydraulic Fluids as Ball Bearing Lubricants

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E. P. Cochran, Jr., Lt. Cmdr. USN (Formerly, Branch Program Officer)*

R. J. Wolfe, Asst. Head, Structural Mechanics & Hydrodynamics Section*

When used as flood lubricants, phosphate ester, phosphate ester-base and water-glycol-base combustion resistant hydraulic fluids significantly reduce the life of angular contact ball bearings below that obtained with petroleum oil. Under a lighter bearing load, the fluids retain the same order of merit as that found for a heavy load. At moderately higher fluid temperatures, bearing life is further reduced. The pressure viscosity relations of the fluids at different temperatures have also been determined for possible correlation with the results of bearing tests. Other related studies have also been made for the purpose of seeking the cause for the reduction in life of bearings lubricated with combustion resistant hydraulic fluids.

INTRODUCTION

Combustion resistant hydraulic fluids have been shown by the authors, in a recent paper[1], to have a significant effect on the life of angular contact ball bearings of a large size operating under high loading with flood lubrication. Morrison[2] has reported similar results for radial bearings of smaller size, also under high loading but lubricated in an entirely different manner. Although these results were obtained for varied conditions with respect to size and type of bearing and manner of lubrication, they are restricted, however, to conditions of high loading. Since the load-life relationship for bearings lubricated with each of the combustion resistant fluids has not been established, general conclusions can not be drawn regarding the life of ball bearings lubricated with these fluids at lighter loads. The assumption that life varies inversely as the cube of the load can not be made with reasonable justification, since the cause for the wide differences in bearing life obtained with the various fluids at a single heavy load may also affect the load-life relationship. It is evident, therefore, that additional experiments to provide corresponding load-life data at lighter loads are needed. This need is emphasized by the large increase in the number of military and industrial applications using combustion resistant hydraulic fluids.

*Material Laboratory, New York Naval Shipyard, Brooklyn 1, N. Y.

(Presented before the American Society of Lubrication Engineers at the 11th Annual meeting, Pittsburgh, Pa., April 6, 1956 under the sponsorship of the ASLE Technical Committee on Bearings and Bearing Lubrication.)

In addition to the above data which are applicable to design, there is also a need for some research to determine the cause of the wide differences obtained with the various fluids as ball bearing lubricants. Such information should prove of great value in the development or improvement of hydraulic fluids as ball bearing lubricants.

The purpose of this paper is to contribute some experimental data showing the trend of the load-life relationship of bearings lubricated with the fluids under consideration and to present some observations which may ultimately be useful in determining the causes for the differences in the lubricating properties of the fluids. The data for light loads are somewhat limited. This limitation will be appreciated when it is realized that life increases very rapidly with decrease in load and that the determination of the load-life relationship with one fluid requires the evaluation of a large number of bearings because of the wide dispersion of lives at any one load.

Three combustion resistant fluids, a phosphate ester, a phosphate ester-base, and a water-glycol-base, were used for this work. The properties of these fluids are shown in Table I, together with those of a petroleum oil intended for the same application.

APPARATUS

The equipment for evaluating the fluids as ball bearing lubricants consists of a fluid transfer system and four bearing testing machines in which eight angular contact bearings are operated to failure.

The fluid transfer system is used to supply a continuous flow of the sample fluid to each of eight bearings mounted in individual housings. The fluid is drawn from the reservoir by a centrifugal pump and passed through a filter, heat exchanger, feed manifold, sight flow indicator and flexible metallic hose, in succession, before entering the bottom of each bearing housing. The fluid flows into the housing on one side of the test bearing, passes through the bearing to the opposite side and is discharged from the top of the housing to the reservoir, through flexible metallic hose and a return line. The temperature of the fluid is measured by means of a dial type stem thermometer inserted into the stream at the discharge from each housing. A similar thermometer is also inserted in the feed manifold

TABLE I

PROPERTIES OF FLUIDS

Fluid	A	B	C	D
Type of Fluid	Petroleum Oil	Phosphate ester	Phosphate ester-base	Water-glycol-base
Color (ASTM)	2	1½	1½	1
Viscosity, SSU at 100°F	182.0	214.0	231.4	280.2
150°F	70.6	68.8	72.9	125.5
210°F	44.3	42.3	44.2	69.5
Viscosity Index	80	<0	16	156
Specific Gravity, 60/60°F	0.8960	1.1470	1.2677	1.0792
Pour Point, °F	–30	–5	–5	< –65
pH	—	—	—	10.0
Neutralization Number	0.08	0.04	0.06	—
Refractive Index, 20° C	1.489	1.553	1.583	1.411
Flash Point, °F	410	535	450	260*
Fire Point, °F	425	600	555	270*
Water Content, %	—	—	—	35.0

*Cleveland Open Cup Method — after water has evaporated.

to permit measurement of the supply fluid temperature. Control of the temperature is obtained by automatic regulation of the flow of cooling water through the heat exchanger and the quantity of fluid flowing through each bearing. A removable magnetic plug is fitted to the bottom of each housing to attract and hold ferrous particles that may be released to the fluid. The main line filter consists of a 60 mesh bronze screen wrapped around a perforated steel cylinder. The capacity of the reservoir and fluid transfer system is 16 gallons.

The bearing testing machines consist of four identical units, one of which is shown in Figure 1. Each unit permits testing two bearings at a time under identical conditions of load and speed. The test bearings (1), size 217 angular contact ball bearings, are mounted opposed in pairs on the drive shaft (2) and are enclosed by housings (3 and 4). The housings are also provided with cylindrical roller bearings (5) for aligning purposes. The shaft is mounted in two ball bearing pillow blocks (6) and is driven by the motor (7) through grooved reduction pulleys (8 and 9) and cog belt (10). The motor is of the polyphase-induction type with a full-load speed of 3450 rpm. A mechanical counter (11), driven through a 100 to 1 speed-reduction gear, is used to indicate the number of revolutions of the drive shaft. Thrust load is transmitted from the levers (12) through hardened steel balls (13) to the housings and thence to the outer race of the test bearings. The load is adjusted by rotation of the handwheel (14) and is measured by means of the dynamometer (15), which indicates one-fifth of the load applied to the bearing because of the 5 to 1 lever ratio. The test bearings take all of the thrust load and are not subjected to radial load other than that imposed by the weight of the housings. The test bearings are push fitted into the housings and onto the drive shaft. The inner race revolves at drive-shaft speed while the outer race is held stationary in the housing which is restrained from rotating by the stop (16). A shaft seal (17) mounted in cover plate (18) prevents leakage of fluid from the housing.

PROCEDURES

The general procedure for evaluating each fluid was to circulate the fluid through the system and flood lubricate the angular contact ball bearings operating continuously under the prescribed conditions until each bearing in two groups of eight failed. Eight bearings from the first group were started simultaneously at eight stations on the machines, and as failure occurred at each station, the bearing was replaced by another from the second group, thereby assuring an equal distribution of bearings among the stations. Additional dummy bearings were used when necessary to permit running all bearings in the second group of eight to failure. Failure was considered to have occurred when either an outer or an inner race spalled, or when a ball spalled, chipped or fractured. Failure was detected by a change in the operating noise characteristics of the bearings. This method was found to be sufficiently effective to permit immediate detection of the presence of a very small spalled spot. Prior to the evaluation of each fluid, the bearings, fluid transfer system, and housings were thoroughly cleaned and then flushed with about three gallons of the test fluid, which was circulated through the system and discarded.

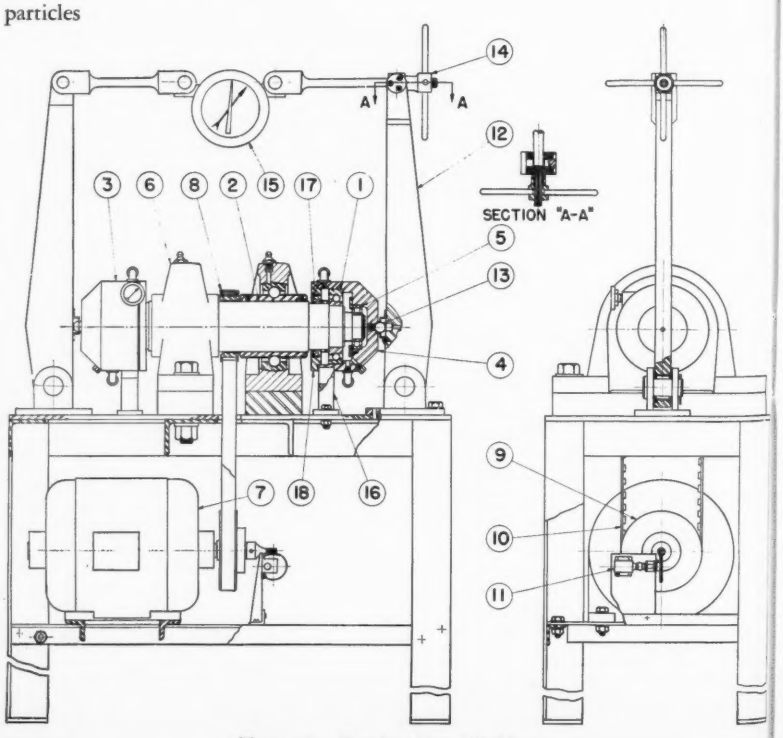

Figure 1. Bearing Test Machine.

The conditions under which the various fluids were evaluated are shown in Table II. Tabulated figures represent the number of bearings tested for each condition. Flow of fluid to each bearing was regulated to 1.5 units on the flowmeter or approximately 0.5 gpm. The speed of the inner race was 2150 rpm. Thrust load is indicated as P, and outlet temperature as T.

TABLE II

TEST CONDITIONS AND NUMBER OF BEARINGS TESTED

	P=12,900 lb		P=8600 lb	P=4300 lb
Fluid	T=150°F	T=200°F	T=150°F	T=150°F
A	32	—	—	—
B	32	16	16	—
C	40	16	16	—
D	16	—	16	16

Two hundred size 217 angular contact bearings of one brand were procured for this work under specifications requiring that the material be part of a single production run. These bearings were randomly selected for the tests but were consumed prior to completion of all the work. Bearings used for evaluating the water-glycol-base fluid under thrust loads of 8600 and 4300 pounds were selected at random from a second group of 200 bearings procured from the same manufacturer under the above specifications.

RESULTS

Data obtained with a phosphate ester and a phosphate ester-base fluid used to flood lubricate angular contact bearings operating under a thrust load of 12,900 pounds and a speed of 2150 rpm are shown plotted in Figure 2 on extreme probability paper. The bulk temperature of the fluid leaving the bearings was maintained at 200°F. The solid straight lines drawn through the data were determined by the "Order-statistics Method" proposed by J. Lieblein[8]. In this method it is assumed that the mode, or highest point of the frequency distribution, occurs at a probability of 0.368. The dotted straight lines shown for comparison represent the distribution of failures for a bulk outlet temperature of 150°F. It is seen that the two lines representing the distribution for the phosphate ester are quite close, indicating that an increase in bulk fluid temperature from 150 to 200°F has little, if any, effect on the life of the bearings. The spread of the two lines for the phosphate ester-base is relatively much greater, indicating that the higher bulk fluid temperature significantly reduces the life of the bearings.

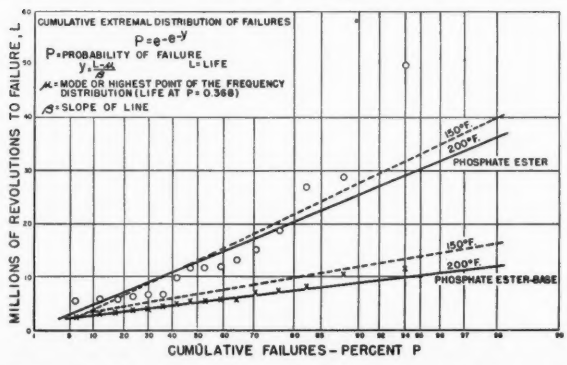

Figure 2. Cumulative Extremal Distribution of Failures of Bearings Operated in Two Hydraulic Fluids.

Load-life data obtained for bearings flood lubricated with the water-glycol-base fluid at a bulk outlet temperature of 150°F are given in Figure 3. Logarithmic coordinates are used in order to permit drawing the load-life curves as straight lines. The large circle at each load represents the modal life determined by the "Order-statistics Method", and the straight line drawn through these points represents the variation with load of the modal life of the bearings operating in this fluid. Also shown in Figures 4 and 5, respectively, are load-life data obtained with a phosphate ester-base and a phosphate ester fluid at two loads.

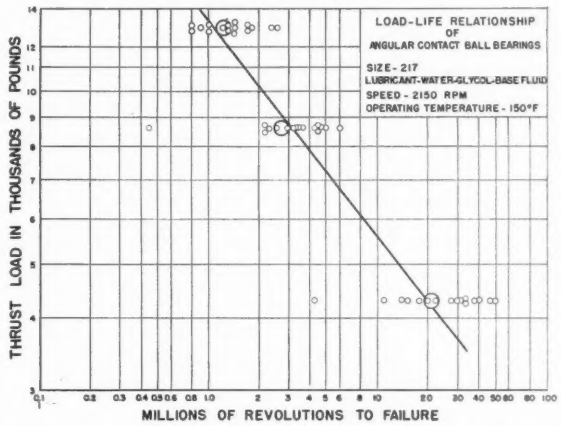
LOAD-LIFE RELATIONSHIP OF ANGULAR CONTACT BALL BEARINGS
SIZE - 217
LUBRICANT-WATER-GLYCOL-BASE FLUID
SPEED - 2150 RPM
OPERATING TEMPERATURE - 150°F
THRUST LOAD IN THOUSANDS OF POUNDS
MILLIONS OF REVOLUTIONS TO FAILURE

Figure 3. Load-Life Relationship of Bearings Operated in a Water-Glycol-Base Fluid.

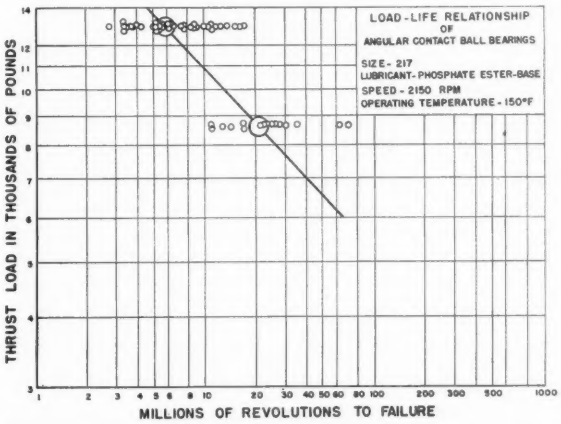
LOAD-LIFE RELATIONSHIP OF ANGULAR CONTACT BALL BEARINGS
SIZE - 217
LUBRICANT-PHOSPHATE ESTER-BASE
SPEED - 2150 RPM
OPERATING TEMPERATURE - 150°F
THRUST LOAD IN THOUSANDS OF POUNDS
MILLIONS OF REVOLUTIONS TO FAILURE

Figure 4. Load-Life Relationship of Bearings Operated in a Phosphate Ester-Base Fluid.

Figure 6 gives a comparison of the load-life lines for bearings operating in three fluids. Also shown is the modal life of bearings operating in petroleum oil under a thrust load of 12,900 pounds. The slope of each line is measured by the value of n in the load-life relationship

$$LP^n = C$$

where L and P are the modal life and thrust load, respectively. Values of n calculated for each of the fluids are given in Figure 6, and the dotted lines shown correspond to a value of $n = 3$.

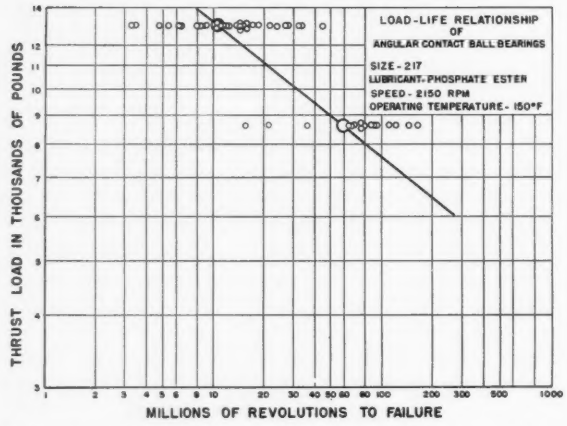

Figure 5. Load-Life Relationship of Bearings Operated in a Phosphate Ester Fluid.

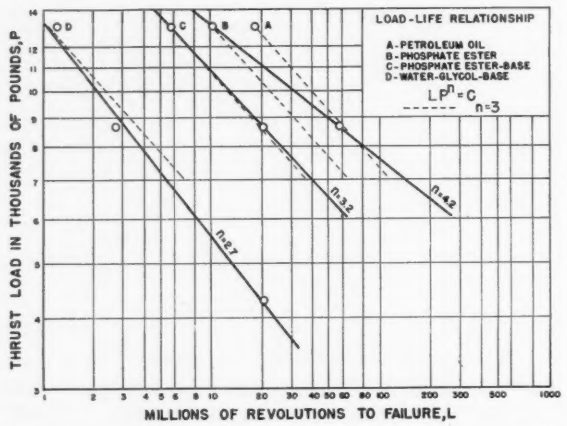

Figure 6. Load-Life Relationship of Bearings Operated in Four Hydraulic Fluids.

DISCUSSION

The load-life relationships summarized on Figure 6 clearly show wide differences in the effect of combustion resistant hydraulic fluids on the modal life of angular contact ball bearings. As expected, the general trend of results is such that the load effect is similar to that found for bearings lubricated with petroleum oil. This effect is appreciable and is measured by the slopes of 2.7 to 4.2 for the load-life lines as compared to the representative value of 3 for bearings operating in petroleum oil[4]. Unfortunately, fatigue data for bearings operating in petroleum oil have not been obtained for more than one load and as a result the corresponding load-life line can not be shown. Although the data obtained for the phosphate ester-base and phosphate ester fluids cover the higher levels of load, extrapolation to lower loads should give reasonable life values because of the general conformity of results to the single pattern established for oil[4]. This procedure should prove expedient until such time that additional data are accumulated to re-establish the load-life lines on a broader basis.

The reduction in bearing life indicated for combustion resistant hydraulic fluids need not be reflected in the life of new designs of hydraulic machinery and equipment. Inasmuch as the load-life lines of Figure 6 show that a small decrease in load will result in a relatively large increase in life, it would appear advantageous to use over-size bearings to offset the reduction in life caused by the fluid. This procedure is commonly followed in bearing selection in order to provide for any factors that may cause a reduction in life. Suitable bearing selection is accomplished by increasing the effective design load through the use of appropriate factors. It would be quite convenient if such a factor could be established to provide for the effect of the lubricant.

Establishment of these lubricant factors requires the accumulation of a vast amount of fatigue data on ball and roller bearings of many types and sizes, lubricated with various combustion resistant hydraulic fluids. There is no doubt that this endeavor would take many years to accomplish and therefore some steps should be taken at this time to develop lubricant factors on the basis of available information and satisfy the immediate needs. Because of the limited amount of data available, it is a foregone conclusion that any factors that may be developed would be no more than rough approximations. However, the wide differences found in the effect of various fluids on bearing life indicates that such approximate factors would still be desirable.

In order to develop simple lubricant factors that would be applicable to most existing bearing catalog data, it is necessary to adjust the load-life lines of Figure 6 so that life varies inversely as the cube of the load. The dotted lines shown on Figure 6 have been drawn to correspond to this inverse cube relationship and to pass through a modal life obtained with each fluid at a load of 12,900 pounds. This load corresponds to ½ the catalog "basic load rating" and has been selected because bearings are usually rated at these high loads. As drawn, the dotted lines predict values of life higher than the actual values for the water glycol-base fluids and lower than the actual values for the phosphate ester-base and phosphate ester fluids. It may be noted from Figure 6 that the actual load-life line for the phosphate ester fluid intersects the dotted line for petroleum oil at approximately 8000 pounds load and suggests that the phosphate ester is superior to petroleum oil as a ball bearing lubricant at lighter loads. Conclusions on this point can not be drawn until the corresponding actual load-life line is determined with petroleum oil as a lubricant. It might be added in this connection that at least one bearing manufacturer[5] indicates that the life of ball bearings lubricated with a petroleum oil varies inversely as the fourth power of the load.

In order to minimize any effects which may be associated directly with the conditions of test, such as size of bearing, temperature, and manner of lubrication, the factor for each fluid should be determined on the basis of direct comparison with petroleum oil. The dotted lines of Figure 6 are designed to serve this purpose. Since these lines are parallel, and correspond to $n = 3$, the lubricant factor, F, is determined from the ratio of modal lives at any one load as follows:

$$F = \sqrt[3]{\frac{\text{Modal Life, Petroleum Oil}}{\text{Modal Life, Combustion Resistant Fluid}}}$$

Accordingly, the lubricant factors determined for the three fluids are:

Fluid	Lubricant Factor, *F*
Water-glycol-base	2.6
Phosphate ester-base	1.5
Phosphate ester	1.2

Application of these factors in the selection of bearings from catalogs should offset the effect of the fluids on bearing life. Although these factors were developed for angular contact bearings, they should prove useful for other types of ball and roller bearings until such time that more reliable factors are developed.

In converting existing equipment over to the use of combustion resistant hydraulic fluids, the problem of reduced bearing life can not, in most cases, be readily solved through the use of over-size bearings. In those cases where bearing design is marginal, reduced life must be accepted and it would be wise to use a fluid which would reduce life the least. In many cases where bearing capacity can be increased through the use of tandem arrangements, or otherwise, the problem is readily solved. Then there are those cases where shaft dimensions, or other factors not directly related to bearing load capacity, dictate the size of bearings and result in the use of over-size bearings which provide adequate life when used with combustion resistant hydraulic fluids. This latter condition probably accounts for the many reports of satisfactory performance in service with these fluids.

Some exploratory investigations into the causes for the differences shown by the various fluids have led to some interesting observations. As a first step in this work, the pressure-viscosity relations for these fluids and a petroleum oil were determined for the Navy by The Pennsylvania State University. The data were obtained for three temperatures and for pressures up to 50,000 psi using a rolling ball type viscosimeter. Average curves determined from the original data are reproduced in Figure 7. The shading is merely intended to isolate the curves according to temperature and clarify the presentation. The rise in viscosity with pressure for the phosphate ester-base and phosphate ester fluids is similar to that for petroleum oil but at a greater rate. The relatively flat pressure-viscosity curves for the water-glycol-base fluid are noteworthy and so different from the others that one might suspect that the relatively low viscosity of this fluid at high pressures may be a contributing factor to its relatively poor behavior as a ball bearing lubricant. However, much further work is required to establish whether viscosity at high pressures is a real factor.

As shown in Figure 2, the lower viscosity of the phosphate ester, occasioned by higher temperature operation, apparently did not significantly affect the modal life of the bearings. The significant reduction in modal life noted for the phosphate ester-base fluid, therefore, may be attributed to temperature effects on the fluid rather than viscosity effects.

An examination of the surface of the ball path of the bearing races revealed differences in the effects of the various fluids on these surfaces. All fluids developed the same characteristic fatigue spalls in the bearing races at failure, but the failures developed by the water-glycol-base fluid

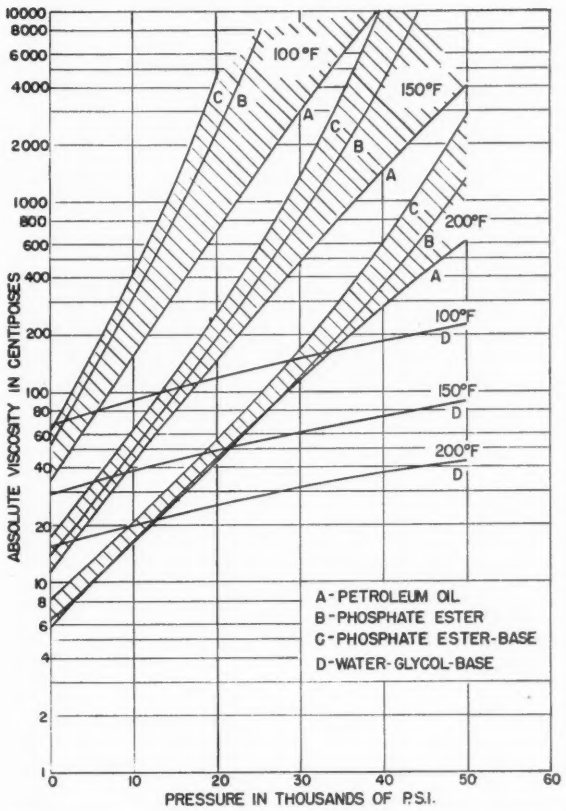

Figure 7. Pressure-Viscosity Isotherms of Four Hydraulic Fluids.

appeared in different stages of development. One of these stages is shown on Figure 8. Because of the difficulty of focusing on a curved surface, photographs were also taken of flat faxfilm reproductions of the ball path. A comparison of the two photographs in Figure 8 reveals that significant detail is not lost by this method of reproduction. The cracks shown on the photographs usually appeared in pairs, concave towards each other. In many instances, the ends of the cracks were joined to form an oval, but the piece did not fall out. Examination of a vertical section across the cracks revealed that the two cracks were joined below the surface, thus dispelling possible evidence that failure started from the surface. On the other hand, the outer periphery of at least eight inner races was ground cylindrically to reveal the area below the ball path. The cylindrical surfaces were polished and the area under the ball path was examined with a microscope. In no case was there evidence of the start of failure from below the surface.

Other differences in the character of the ball path surface after failure are shown by the faxfilm reproductions on Figure 9. Each of these bearings had run for approximately 10 million revolutions to failure, except for the bearing lubricated with water-glycol-base fluid which had run for about 1 million revolutions before failure. Microscopic pits appear on all surfaces but in increasing number for ball paths lubricated with phosphate ester, petroleum oil, phosphate ester-base, and water-glycol-base fluids in the order mentioned. A reproduction of an unused ball path is also shown to serve as a basis for comparison. It may be significant that the two fluids, phosphate

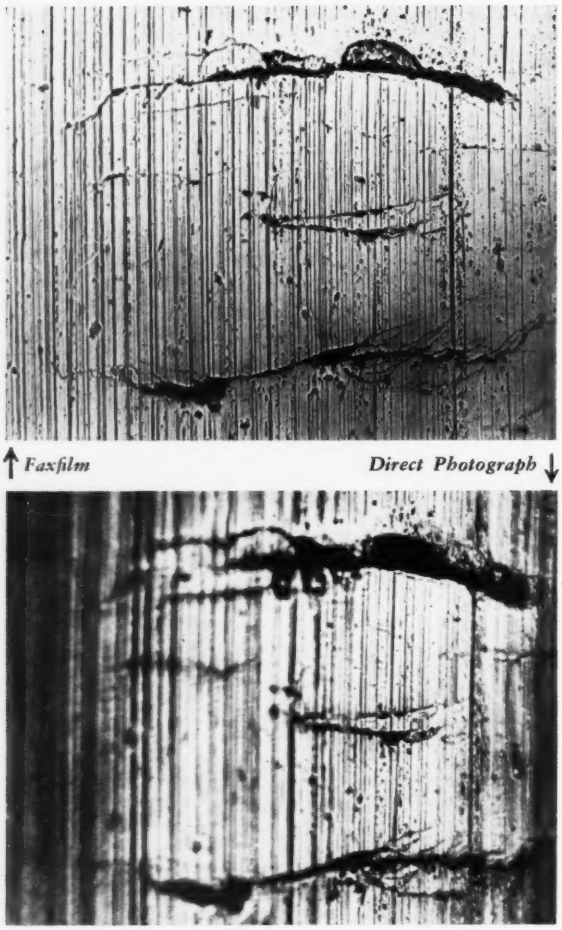

Figure 8. Faxfilm Reproduction and Direct Photograph of Incipient Spall in Ball Path of Bearing Operated in Water-Glycol-Base Fluid. (40X)

ester-base and water-glycol-base, which gave the shortest bearing modal lives, show the greatest number of these microscopic pits.

CONCLUSIONS

Combustion resistant hydraulic fluids have a significant effect on the life of angular contact ball bearings. The load-life lines for bearings operated in these fluids conform to the same general pattern as that established for bearings operated in petroleum oil.

The reduction in bearing life obtained with these fluids need not be reflected in the life of new machinery and equipment nor, in many cases, in the life of existing equipment. Since a small decrease in load results in a large increase in life, the effect of the fluids may be offset by an increase in bearing size. The following lubricant factors are proposed for correcting equivalent design loads determined from current bearing handbooks.

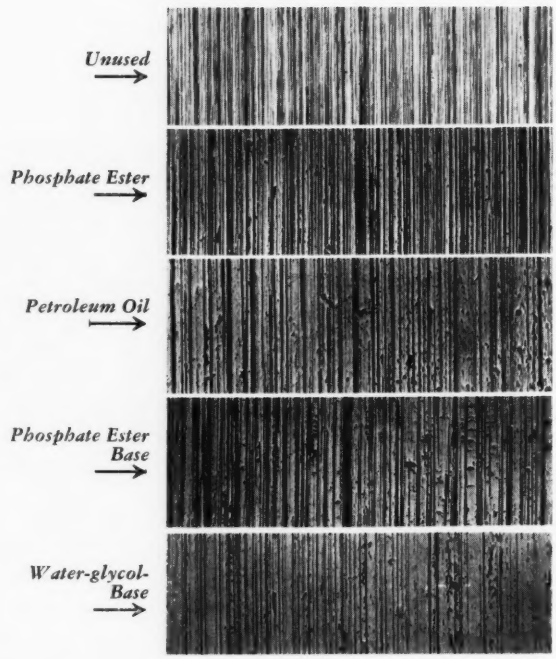

Figure 9. Faxfilm Reproductions of Surface of Ball Path of Bearings Operated in Four Hydraulic Fluids. (40X)

Fluid	Lubricant Factor
Phosphate ester	1.2
Phosphate ester-base	1.5
Water-glycol-base	2.6

Application of these factors to other types of ball and roller bearings would appear to be desirable until such time that more reliable values are established.

The causes for the differences in the effect of the fluids on bearing life have not been determined. Much further study is required in this connection.

ACKNOWLEDGEMENT.

The assistance of Mr. W. Berkson of the Mechanics Branch of the Material Laboratory, New York Naval Shipyard, in conducting the life tests on the bearings, and of Mr. A. Delman of the Chemistry Branch in developing the faxfilm records of the bearing surfaces, is gratefully acknowledged.

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3rd ASLE-ASME Lubrication Conference
October 8-9-10, Atlantic City, New Jersey

Physico-Chemical Investigation of Engine-Oil Performance

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A systematic analysis of engine-oil deterioration and related phenomena has been accomplished by correlating pertinent oil properties with results from appropriate engine tests. Engine conditions were so selected that performance would be determined largely by one, or at most two, factors and comprised: (a) a cycling sequence at low temperatures (characteristic of city driving); (b) moderate-temperature operation (resembling winter driving on the highway); (c) hot diesel operation. The oil properties included deflocculating ability, catalyzed oxidation rate, and corrosivity to bearings caused by oil oxidation. They were measured over a sufficiently wide temperature range so as to cover conditions prevailing in all regions within the engine. With typical commercial fuels and at usual (relatively high) additive concentrations, cleanliness in spark-ignition engines at low and moderate temperatures requires the disposal of partial fuel-combustion products. High-temperature (gasoline and diesel) engine cleanliness is governed largely by the retardation of oil oxidation and dispersal of the eventual oil-deterioration products. Nearly precise prediction of (copper-lead) bearing corrosion in test engines may be obtained from a facsimile bearing installed in an oxidation cell, operated at engine bearing temperatures and at the low degrees of oxidation generally found in crankcase oils. The foregoing correlations help to interpret engine results and establish mechanisms but do not furnish an ultimate criterion for oil performance. Overall evaluation can be conducted only in the engine, for it alone assesses simultaneously, under actual operating conditions, such diverse functions as detergency and prevention of corrosion and wear.

INTRODUCTION

The past 15 years have seen intense research activity on additive lubricating oils. To provide tools both for additive evaluation and for exploring experimental variables, laboratory engine-test procedures were gradually developed which reproducibly and validly measure pertinent factors. It naturally followed that a connection should be sought between physico-chemical mechanisms and performance. Accordingly, workers in this field have been devising laboratory methods for measuring certain significant properties so that they could be compared with oil behavior in the engine. The following study was undertaken to integrate these relationships into a consistent pattern, at the same time filling in any gaps in basic information, wherever they might appear.

The extreme range of service conditions encountered has focused special attention on the dependence of additive-oil behavior on temperature. Hence, the essential feature in the design of both laboratory and engine tests is complete coverage of the entire practical range, from 30 to 250° C. To ensure reliable results, the engine was operated on the base oil before and after each test on the experimental oil so that any inherent base-line shift could be assessed safely.

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The new methods for measuring oil properties are described in earlier publications, [1,7] and the engine test procedures are given in Appendix A.

The primary mechanisms were identified by which engine cleanliness and the protection of critical parts against corrosion may be achieved under clearly specified types of service. The scope was limited to the correlation of performance given by definite additives in the oil with characteristic physical and chemical properties of the blend. In effect, the engine was regarded as a system of chemical reactors.

Since all the oils used are considered sufficiently well characterized by their properties, no purpose would be served by detailed chemical identification of their composition. A complete set of chemical and physical properties is presented in Table I. Because of the high additive levels employed, it is believed that the results possess rather general applicability, the only exception being very unstable (not well-refined) stocks.

ENGINE CLEANLINESS

The ability of motor oils to keep engines clean, especially in the piston and crankcase areas, is generally called "detergency." Few terms have been used so loosely and caused so much confusion in petroleum technology, primarily because it covers a group of quite unrelated phenomena. It is shown below that different operating condi-

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S. J. Beaubien

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Table I

PROPERTIES OF THE OIL BLENDS TESTED

Oil	Base Oil[a]	Ca Phenate			Basic Calcium Sulfonate			Neutral Calcium Sulfonate	Mixtures of A and B			Heavy-metal Sulfonate (neutral)		Lime Sol	High-Temp. Oxid. Inhibitor	Polymer	
		A_1	A_2	A_3	B_1	B_2	B_3	C	D_1	D_2	D_3	E_1	E_2	F_1	F_2	G	A H_1	B H_2
Deflocculating Ability[b]:																		
	n ac	n ac			n ac			n ac	n ac		n	ac	n ac				n ac	n
pD_5^w at 30°C	0.6 1.5	2.4 3.0			3.4 2.5			>2.9 2.6	2.8 3.1		2.3	—	2.9 –				>5 3.3	4.6
pD_5^w at 100°C	0.3 0.9	1.8 3.1			2.4 3.0			3.3 >2.3	1.5 3.1		1.9	2.80	2.1 –	equal to		no effect	4.6 2.7	
pD_5^w at 150°C	0.2 0.8	1.2 3.2			2.1 3.3			2.5 (2.1)	1.4 2.9		1.6	2.60	1.0 2.25	that of		"	4.3 2.8	
pD_5^w at 180°C	– –	1.0 3.1			1.6 3.3			>0.5 –	1.2 2.9		–	–		base oil		"		
Carbon Retention (%) at 30°C	1	8			44	63										"	45	(28)
Antioxidant Effectiveness[c]:																		
at 150°C (Dornte Apparatus) ccc	1	10.3	13.9	30	1.3	1.4	2.6	–	–	–	–							
at 150°C (Cu/Pb Thrust bearing in oxidation cell):	1	7	11	7	0.9	1.0	1.1	0.13	–	7.9	5.7	(120°C) 3.3	(120°C) 0.65	0.35				
at 260°C (Static cell) with Cu:	–	4.6;3.1					1.0;0.75	8.9			2	11.1	5.6	1.9		6.96		
with ccc:		3.1;2.0					1.3;0.63	4			4.4	3.7	0.9			3		

a) The base oil is a highly refined (straw colored) western petroleum fraction, viscosity at 100°F = 1.32 Stokes, at 210°F = 0.104 Stokes.

b) The deflocculating ability of the additive was measured in the base oil when marked (t), and in a heavy medicinal white oil when marked (w); the columns (n) and (ac) stand for "neutral" and "acidic" carbon black, respectively; pD^w = log (resist. of susp. in additive blend ÷ resist. of white oil suspension) at 10 sec^{-1} shear rate.

c) Antioxidant effectiveness = oxidation rate of base oil ÷ oxidation rate of additive blend, Cu = copper powder catalyst, ccc = crankcase catalyst (primarily $FeCl_3$); all the work at 260°C was carried out in a heavy aero-engine oil to avoid volatility complications.

tions may require widely different oil properties in order to maintain satisfactory cleanliness.

Low-Temperature Operation

City driving conditions, involving frequent stop-and-go operation at relatively low jacket and crankcase temperatures, are known to cause heavy sludging in the oil followed by oil-ring plugging and consequently high oil consumption. Duplication of such operation in the laboratory engine was particularly difficult. A temperature-cycling operation was finally evolved that correlated very well with field performance, especially in regard to sludging and oil-ring plugging (Appendix A).

Although all engine operations subject the lubricating oil to a certain amount of relatively high-temperature exposure while it circulates through the upper ringbelt zone, it was felt that, because of the low jacket temperature and short running time of this test, no volume element of the oil would be exposed to high temperature long enough to undergo extensive oxidative or thermal degradation. The suspicion that engine dirtiness is caused by condensed fuel-combustion products rather than by changes in the oil was strongly supported by direct observation of the blow-by products "raining" into the engine and indirectly by the observation that forced ventilation of the crankcase reduced sludge formation and engine deposition almost to the zero point, or at least as much as with the very best "detergent" on the market.

Published analyses of low-temperature engine sludge have shown that it is primarily a water-in-oil emulsion stabilized by solid particles.[10] Since the ability of solid particles to act as emulsion stabilizers depends critically upon the strength of their mutual adhesion (flocculation [11, 14]), it was postulated that such sludge formation could be suppressed by suitable deflocculants. The deflocculation efficiency of surface-active substances is closely related to their strength of adsorption on the surface of the particles which are to be deflocculated. [9, 15] Since the strength of adsorption of additive is strongly influenced by the chemical nature and the total surface area of the particles, both properties were ascertained for low-temperature engine sludge. The acid-base reactivity was found to be neutral (surface pH ~ 6.5) and the specific area (by nitrogen adsorption) was about 30 m^2/g.

Multiplication of the total weight of sludge particles usually collected in the crankcase (up to 2 per cent by weight) by the specific surface area and the amount of additive in equilibrium with unit area of deflocculated surface(1) then permits quantitative assessment of the required net amount of an additive suitable for this type of surface. The corresponding correlation between degree of deflocculation of a neutral model carbon black at the average temperature of "low-temperature" engine operation and the observed engine sludge (shown in Figure 1) confirms the proposed mechanism of sludge prevention. The importance of the chemical reactivity of the particle surface is illustrated by the fact that the *basic* additive A (cf. Table I) is an excellent deflocculant for *acidic* carbon black(2) but a poor deflocculant for neutral b'ack.(3) Incorrect choice of the deflocculation model substance would therefore have vitiated the correlation and led to confusion concerning the mechanism involved. However, in spite of its broad applicability, this correlation between the engine and deflocculation in dry suspensions is not always reliable.

Since water is present in the engine, only those deflocculants that resist displacement from the oil/solid inter-

(1) Derived from deflocculation data.
(2) Channel black.
(3) Acetylene black.

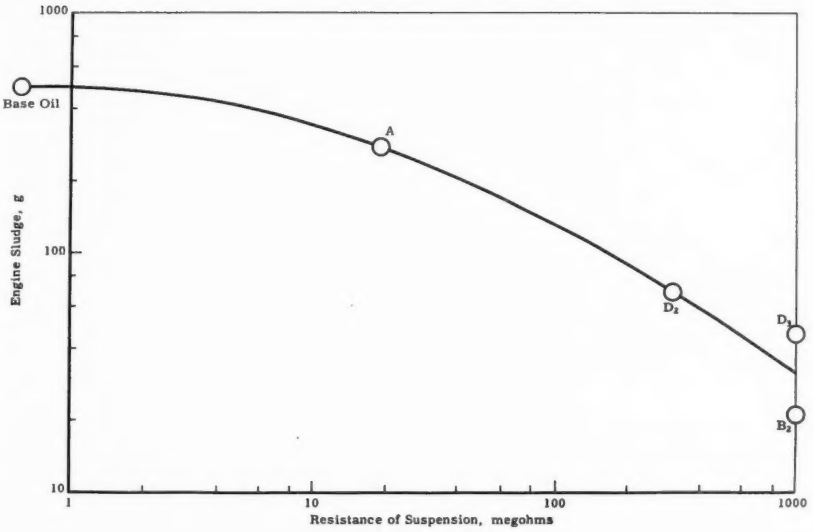

Figure 1. Qualitative (static-electrode) deflocculation rating (resistance of carbon black suspension) vs. low-temperature engine sludge.

face by water may be expected to function effectively. Measurement of deflocculating ability under such conditions or of resistance to displacement is rather difficult. In lieu of direct measurement, a "water-extraction" test[4] has been devised that correlates very well with sludging in the low-temperature engine, as shown in Figure 2. The importance of this property is demonstrated by several blends with good deflocculating ability in dry but not in "wet" systems.

It then appears that the problem of low-temperature sludging may be essentially solved by preventing the flocculation of particles (presumably polymerization products of partially oxidized fuel and inorganic salts derived from fuel additives) and, thereby, preventing the stabilization of water-in-oil emulsions. The severity of the operating conditions, and hence the demand upon the additive, is therefore a function also of the fuel quality (sulfur content, gum-forming tendency, etc.).

Moderately Low-Temperature Service

Continuous car operation under normal driving conditions, especially in the cold zones of the United States, does not lead to appreciable sludge formation in engines but promotes the deposition of lacquer on the piston skirts. The FL-2 Test, devised by the CRC committee[8] and described in Appendix B, is intended to simulate such operation. However, correlation with the performance of current car models is unknown. The choice of FL-2 as a moderately low-temperature test was largely dictated by the convenience of having a large amount of well-established data already available for comparison.

Inspection of FL-2 operating conditions suggests that here, as in the sludging test, the condensable fuel and fuel-oxidation products are more important than oil oxidation as a source of engine dirtiness. However, the nature of the deposit-forming mechanism must differ appreciably from that prevailing under more drastic sludging conditions, since there is—with one exception to be discussed later—no correlation between engine cleanliness rating (largely determined by piston varnish) and either the deflocculation characteristics of the additives or the oxidation stability of the oil blend.

The chemistry of deposit formation readily suggests a suitable basis for correlation. Polymerizable components of partially oxidized fuel comprise some of the original fuel olefins, aldehydes, and especially the hydroxy-acids. Saponification number[5] and (direct) oxygen determination of piston-lacquer samples from FL-2 runs give values agreeing quite well with the supposition that lacquer is primarily the condensation polymer of C_8 hydroxy-acids.

As is well known, the polymerization of hydroxy-acids (to oil-insoluble lacquer) may be prevented by their conversion to the corresponding soaps, e.g., by neutralization with alkali.[5] Consequently, FL-2 engine cleanliness should correlate with the base neutralization number of the lubricating-oil blend. Indeed, such a correlation has been found rather satisfactory for strongly basic compounds ranging from alkaline earth phenates through "basic" petroleum sulfonates to colloidal suspensions of lime and calcium carbonate (Figure 3). Since different sources of basicity are consumed at different rates in the engine, there is somewhat better correlation of piston lacquer versus base life in the engine (i.e., time until disappearance of measurable free basicity in the oil). The improvement in correlation is particularly striking where blends of low additive concentration have been examined in different laboratories of our organization,[6] indicating the role that engine severity plays in the depletion rate of additives.

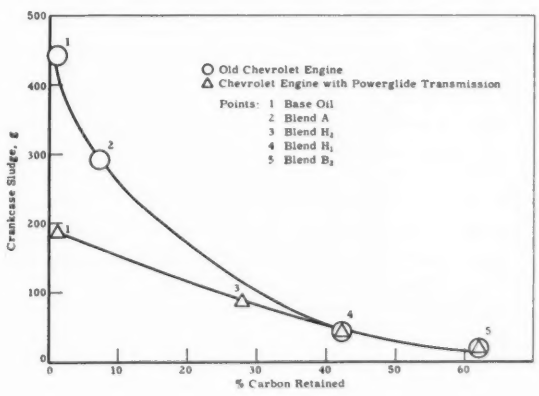

Figure 2. Shawinigan carbon-black retention (gravimetric) at 30° C. vs. sludge formation in a low-temperature (ES-2) engine test.

(4) Appendix B.
(5) Typical values: saponification number, 362 mg KOH/g (= 154 equivalent weight) = 20.8 per cent oxygen if in a polyester. Direct oxygen determination gives 21.0 per cent oxygen.
(6) We are particularly indebted to the Wood River Research Laboratory of Shell Oil Company for some of the data of Figure 3.

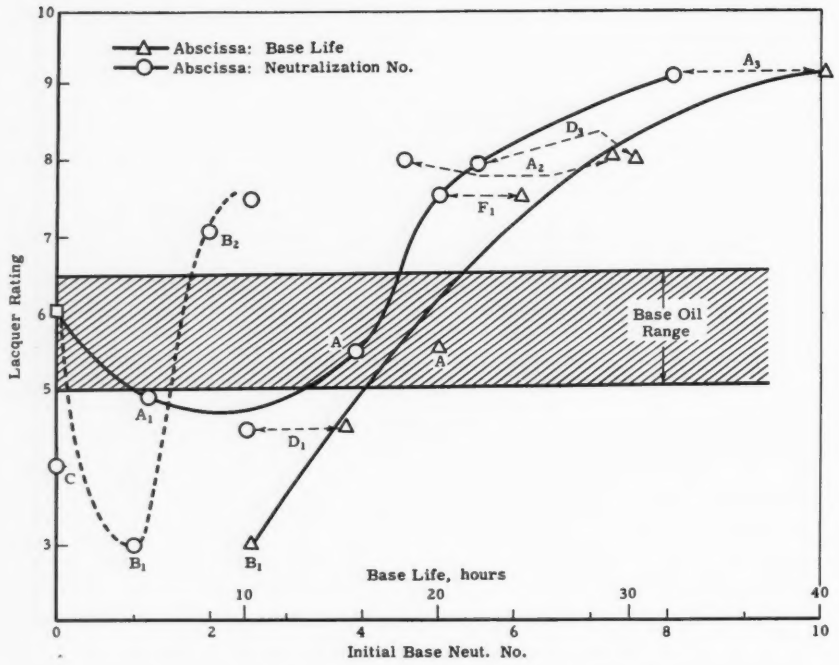

Figure 3. Automotive lacquer (FL-2) vs. free alkalinity.

The observation of actual impairment of engine cleanliness (in this test) by small concentrations of additives that are very effective at high concentration calls for explanation but none has yet been found that is fully satisfactory. There is independent evidence that condensed sulfur acids from fuel combustion are able to displace hydroxy-acids from their alkaline earth salts in the depleted basic additive and react with them to form rather surface-active organic sulfates. These compounds may then be responsible for the reduction in engine cleanliness by rapidly depleting low-additive blends. Needless to say, commercial additive blends are nowadays at concentration levels that preclude additive depletion at any time during normal car-operating and lubrication schedules.

The chemical method just described of maintaining engine cleanliness under FL-2 conditions is not the only one at the disposal of the oil technologist. Additives of exceedingly great surface activity under given operating conditions—expressible in terms of the very high degrees of deflocculation which they provide—are probably capable of emulsifying the partial fuel-combustion products and deflocculating the final polymers so effectively that they do not deposit anywhere in the engine. Some of the newer high-molecular-weight surfactants of low or negligible alkalinity exhibit degrees of deflocculation several orders of magnitude above those of even the most active lower-molecular-weight substances (e.g., petroleum sulfonates) and provide excellent engine cleanliness. However, such additives possess certain shortcomings since they offer no protection against scuffing and, because of their inability to neutralize acids, against wear. They may, of course, ultimately be incorporated along with other additives into well-balanced formulations.

High-Temperature Operation

Heavy loads lead to high crankcase and especially to high main-bearing temperatures (which may exceed that of the oil supply or crankcase by more than 50° C.). Appropriate bearings are required here, usually copper-lead, or, more rarely, silver or aluminum. Such high-temperature levels, as well as contact with lead, copper, or silver followed by solution of these catalytically active metals, accelerate bulk-oil oxidation.

Moreover, in large engines (gasoline or diesel) the ratio of piston-ringbelt surface to piston displacement is so much smaller than in the average passenger car that piston temperatures are appreciably higher, a condition which is further aggravated by heavy loading. High compression ratios are often still another contributing factor. Hence, oil deterioration occurring in the upper zone of these more severe engines assumes greater significance than in automobiles.

In general, extensive oxidation has two undesirable consequences: (a) acidic products may corrode the bearing metals drastically; (b) insoluble products deposit on

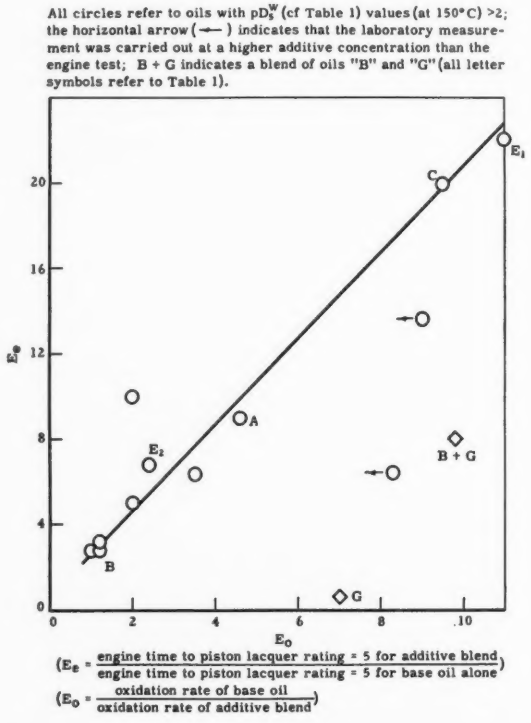
All circles refer to oils with pD_t^W (cf Table 1) values (at 150°C) >2; the horizontal arrow (→) indicates that the laboratory measurement was carried out at a higher additive concentration than the engine test; B + G indicates a blend of oils "B" and "G" (all letter symbols refer to Table 1).
E_e
E_o
B + G
$(E_e = \frac{\text{engine time to piston lacquer rating = 5 for additive blend}}{\text{engine time to piston lacquer rating = 5 for base oil alone})$
$(E_o = \frac{\text{oxidation rate of base oil}}{\text{oxidation rate of additive blend}})$

Figure 4. Additive effectiveness factor (E_e) in the L-3 diesel engine test vs. that (E_o) in the laboratory high-temperature oxidation test (at 260° C.) for various additives.

the piston ring lands and skirts. Since the reaction rate at the temperature of the ring lands ($\sim 250°$ C.) differs by several orders of magnitude from that at the maximum crankcase or bearing temperature ($\sim 150°$ C.), the comprehensive evaluation of oils must take into account their oxidation resistance at 250° C.[7] Interestingly enough, even the most effective oxidation inhibitors for this range were entirely unable to maintain engine cleanliness under high-temperature conditions unless they were admixed with high-temperature deflocculants, or unless they themselves also possessed deflocculating ability. On the other hand, high-temperature deflocculants, either without additional oxidation inhibitors or without antioxidant qualities of their own, were unable to keep L-3 (hot) diesel-engine pistons clean. Such a correlation is shown in Figure 4 where the improvement in diesel-engine piston varnish is plotted against the high-temperature oxidation stability of additive blends with high-temperature deflocculating ability as a parameter.(7) Since the particle surface of high-temperature sludge proved to be acidic, deflocculation here was measured on an acidic model substance (channel black).

Whereas the most desirable proportions of oxidation resistance and of deflocculating ability depend on the hydrocarbon composition and on the chemistry of oxidation of the base oil, it is indicated that even in the presence of the best antioxidant enough varnish is produced by oxidative and fuel-sulfur acid[6] attack on the oil to require a high-temperature deflocculant.(8) The need for investigating high-temperature performance in terms of high-temperature properties is apparent from the complete lack of correlation between diesel-engine cleanliness and conventional oxidation resistance at 150° C. or room-temperature deflocculation. The explanation is, of course, that additives differ greatly in the temperature coefficient of their effectiveness. (A discussion of the reason for these individual characteristics would be beyond the scope of this paper.)

The sharp temperature difference between the piston zone and the crankcase permits an estimation of the quantitative relations between engine and laboratory oxidation. It may be assumed that the oxidation reactions in a given volume element of oil proceed mainly at high temperature and slow down greatly as soon as the oil leaves the high-temperature zone. Under carefully controlled conditions, with saponifiable oil oxidation products as "tracers," it is found that on the average the oil stays but 0.5 to 1 per cent of the time in the high-temperature zone. The correlation between a 0.1- to 2-hr. oxidation rate measurement at 250° C. and the 20- to 300-hr. engine test is therefore entirely reasonable.

CORROSION PHENOMENA

Bearing Corrosion

Oil oxidation in heavy-duty engines equipped with copper-lead bearings inevitably leads to corrosive attack. This is a well-known phenomenon and its chemistry has been completely clarified.[3, 4, 13] However, laboratory tests which have been devised to predict this characteristic of engine oils so often give results completely at variance with field performance that engineers justly refuse to recognize the laboratory data as meaningful. Hence the quantitative relations were reexamined and a plausible explanation was derived.

Several years ago it was discovered[13] that the rate of bearing corrosion (i.e., of dissolution of lead from the copper matrix) depends upon organic-acid concentration (under oxidizing conditions, i.e., in the presence of sufficient peroxides) as shown in Figure 5. The cause of the discontinuous rise at some critical acid concentration is still obscure, but its occurrence is very general. Tolerable bearing-corrosion rates are of the order exhibited by the lower left branch of the curve. A significant test should, therefore, measure either the "low" corrosion rate in the precritical (oxidation) acid-concentration range, or determine the time required to reach the critical concentration.

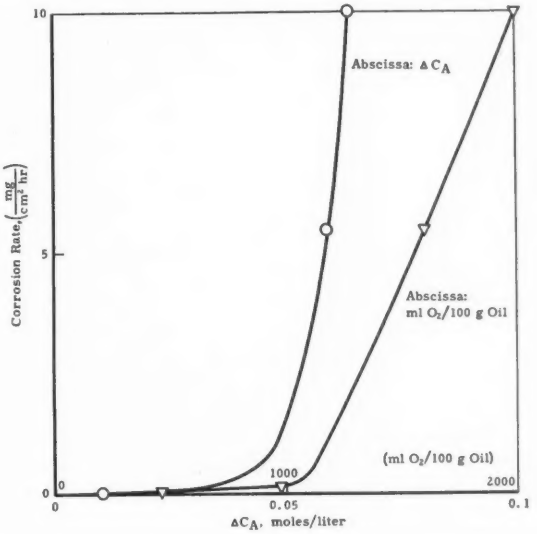

Figure 5. Corrosion rate vs. oxidation-acid concentration (or oxygen absorption) in laboratory test at 150° C.

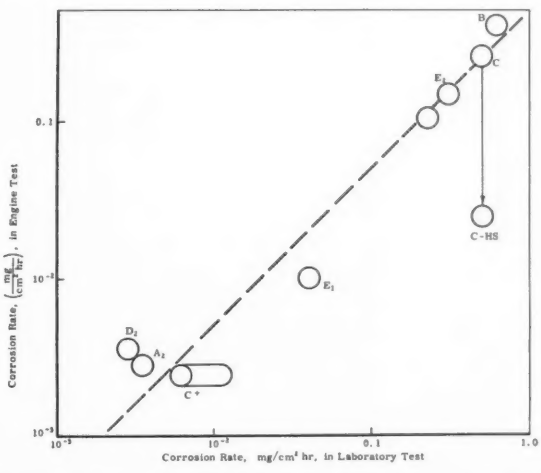

Figure 6. Corrosion rate of copper-lead bearings in L-3 diesel engine test vs. laboratory test at 120° C. (Broken line has unit slope.)

(7) A similar correlation is to be expected for the piston varnish in the L-4 high-temperature gasoline engine test, but it has not been worked out in similar detail.

(8) All the L-3 data were obtained with fuels of up to 1 per cent sulfur content, comparisons of additive blend and base oil being made at constant fuel-sulfur level. Fuels with very much higher sulfur content may fall outside the correlation.

Since the common laboratory bearing-corrosion tests were extended to oxidation-acid concentrations well beyond the critical, the measured corrosion rates bore no relation to those observed in engines. Modification of the test operating conditions to match those prevailing in bearings leads to excellent correlation between laboratory and L-3 test results, as shown in Figure 6. Similar agreement was found to hold for operation at higher crankcase temperature and high-temperature laboratory tests, provided that the oil is sufficiently well inhibited to last through the service without forming the "critical" acid concentration.

When the oil is oxidized beyond the critical point in service, another approach may be useful. Insertion of a bearing-metal strip in the oil-circulation line of the test engine permits frequent measurements of oil corrosivity in situ. (Repeated dismantling of the main bearings would be rather time-consuming and might even invalidate the results.) Comparison with main-bearing weight losses shows that the impinging oil stream corrodes the test strips in a representative manner. Since dissolution of bearing metal (i.e., oxidation catalyst) in the oil accelerates the oxidation and thereby the corrosivity of the oil, the "induction" periods may be delineated quite sharply both in the engine and in the laboratory test. Figure 7 shows rather good correlation between the corrosion-induction periods in the engine and the oxidation-induction period in the laboratory Thrust Bearing Corrosion and Oxidation test [3, 12] under similar operating conditions.

The frequent incidence of nearly one-to-one agreement here does not exclude the possibility of serious exceptions. Such an occurrence is shown in Figure 6 as point (C-HS), where a high-sulfur fuel improved the engine-bearing performance of the additive through a specific mechanism that could not possibly have been observed in the laboratory oxidation equipment. On the other hand, some additive-free mineral oils show little bearing corrosion in the laboratory test in spite of a high oxidation rate, but exhibit the high corrosion rate resulting from their oxidizability in the engine, probably because fuel-combustion products interfere with the very slight protective action derived from naturally occurring sulfur compounds. Such interference by the fuel will invariably necessitate final examination in an engine, but the value of the laboratory measurement in screening additive-containing oils with fair reliability can hardly be denied.

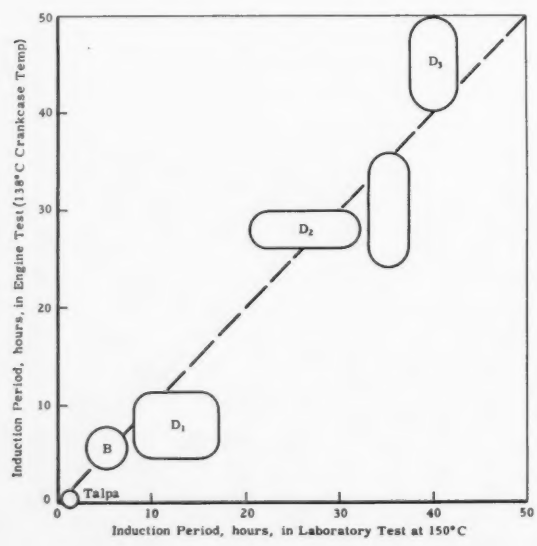

Figure 7. Bearing-corrosion induction period in Chevrolet L-4 test vs. oxidation-induction period in laboratory test.

Corrosive Engine Wear

In agreement with the hypothesis that the major portion of engine wear under low-temperature conditions is caused by acidic combustion products, previous investigators had shown that the wear-prevention ability of certain additives in cold diesel service could be predicted fairly well from their alkalinity.[2] Qualitatively, the same holds for passenger-car gasoline engines. Detailed analysis, however, reveals that wear behavior cannot easily be predicted quantitatively in the rather more temperamental gasoline engine. Instantaneous wear and instantaneous alkalinity in a given type of crankcase oil may remain quite reproducibly related through many runs, but the rate of alkali consumption (i.e., the engine severity) varies so much among engines[(9)] of identical construction as to preclude any accurate prediction of corrosive wear from oil properties.

All attempts to reproduce engine wear in laboratory bench tests in a correlatable manner have thus far been signally unsuccessful. The authors have tried several methods and at times obtained rather plausible values, only to be confronted by a completely inexplicable result as soon as a very different type of additive was examined. This experience supports the older observation that antiwear action involves interactions among several different mechanisms. Engine testing is therefore likely to remain the most reliable guide in the development of antiwear agents for some time to come.

CONCLUSIONS

In summary, the expression of oil behavior in engines in terms of simple physico-chemical properties or processes is possible only where one or two mechanisms are predominant. Conversely, the relation of a given performance feature to one or a combination of two definable oil properties would suggest that this particular type of performance is determined by only one or two definable mechanisms.

Low-temperature sludging and medium-temperature varnish both appear to depend upon a single factor, namely, partial-combustion products of the commercial fuels and their polymers, since their agglomeration and/or deposition may be prevented by deflocculation or inhibition of polymerization. On the other hand, high-temperature varnish, although produced by a single mechanism (oxidation of the lubricating oil),[(10)] still requires for its prevention the simultaneous operation of two mechanisms (reduction of the oil-oxidation rate and dispersion of the inevitable oxidation products by means of deflocculants).

Bearing corrosion in heavy-duty service also proceeds chiefly by one mechanism, namely, by carboxylic acid attack under oxidizing conditions, since corrosion rates in the engine correlate excellently with those in a simple bench device where oil oxidation is the only possible source

(9) As had been mentioned in connection with FL-2 varnish results above.

(10) And to some extent by the attack of sulfur oxides from the fuel on the lubricating oil in the ring grooves.

of corrosivity. Oil behavior in any simple bench device cannot predict corrosive engine wear, although this has been demonstrated to result primarily from sulfur-acid attack on cylinder walls and piston rings, probably because the simultaneous functioning of several mechanisms is required for effective corrosion prevention.

Hence it appears that some of the more important aspects of the field performance of lubricating oils may be subjected to rational analysis. The underlying principle followed thus far, namely, the separation of significant functions into temperature regions, may not be the only one worthy of consideration, but it has certainly proved its fruitfulness. Further work along such lines should ultimately lead to the establishment of a reasonable comprehensive theory to encompass all types of engine behavior.

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APPENDIX A

Engine Test Conditions

1. Low-Temperature Sludging.

Purpose: To obtain the crankcase sludge characteristics of city driving conditions. The results of this accelerated test correlate well with observations in cars driven in the San Francisco Bay Area.

Engine: Chevrolet, 6-cylinder, spark-ignition, liquid-cooled.

Conditions: 27 hours cyclic operation comprising periods totaling 21 hours of programmed low- and moderate-temperature running to simulate city driving (oil temp. —7 to +66°C, jacket temp. —18 to +69°C) alternating with two 3-hour periods of high-temperature cruise (oil temp. 85°C, jacket temp. 79°C) on automotive fuel.

Engine data: crankcase deposit (in grams); piston deposit (visual).

2. Moderate-Temperature Piston Varnish (FL-2) Test.

Engine: Same as No. 1.

Conditions. BMEP: 66 psi; Speed: 2500 rpm; Load: 45 hp; Test duration: 40 hr.; Oil temp.: 74° C.; Jacket temp.: in 29° C., out 35° C.; Intake air temp: 24° C.

Engine data: piston varnish (visual rating).

3. Hot Diesel (L-3) Test.

Engine: Caterpillar D-4400, 4-cylinder diesel, liquid-cooled.

Conditions. Speed: 1400 rpm; Load: 37 hp; Test duration: (nominally 120 hr.) until a certain degree of dirtiness has been reached; Oil temp: 100° C.; Jacket temp: 93° C.; Intake-air temp: 60° C.; Fuel: UO-10 M.

Engine data: piston deposits (visual rating); ring sticking (visual rating); bearing weight loss.

4. Heavy-Duty Gasoline Engine (L-4) Test.

Engine: same as No. 1, but with copper-lead bearings.

Conditions. BMEP: 35 psi; Speed: 3150 rpm; Load: 30 hp; Test duration: 36 hr.; Oil temp: 138° C.; Jacket temp: in 88° C., out 93° C.; Intake-air temp: 27° C.

Engine data: piston varnish and cleanliness of other engine parts (visual rating); bearing weight loss.

APPENDIX B

Laboratory Tests

1. Deflocculation Test.

Equipment: described in Reference 1.

Procedure: Test blend is mixed and equilibrated with the carbon-black concentrate for one week (if at room temperature). Then the blend is examined over the temperature and shear-rate range intended in the cell of Reference 1. The data are plotted and the electrical resistance at a standard low speed, e.g., 10 sec^{-1}, is selected for comparison with the resistance of the corresponding carbon black in neat white oil.

2. Water-Extraction Test.

Procedure: The requisite amount of carbon-black concentrate is weighed and mixed into the test blend. After homogenization, the suspension is equilibrated at test temperature. Then a suitable amount of water is emulsified into the oil with a high-speed stirrer. While most additives are not sensitive to the precise amount of water used, some additives retain very little carbon in the oil with large doses of water. In that case good correlation with the engine can be expected only if the amount of water is similar to that encountered in the engine crankcase, often of the order of 5 per cent in low-temperature operation.

The emulsion is centrifuged at the test temperature under conditions appropriate to the carbon-particle size and oil viscosity, i. e., such that primarily the emulsion droplets and not the carbon particles are sedimented. Following sedimentation, a sample is pipetted from a standard position in the centrifuge tube and analyzed gravimetrically for carbon-black concentration.

3. Bearing-Corrosion Test.

Procedure: The test cell of Reference 12 is closed and equipped with oxygen-circulation inlet and outlet. The oxygen absorption is measured and recorded automatically. Bearing corrosion is measured by weighing as discussed in Reference 12.

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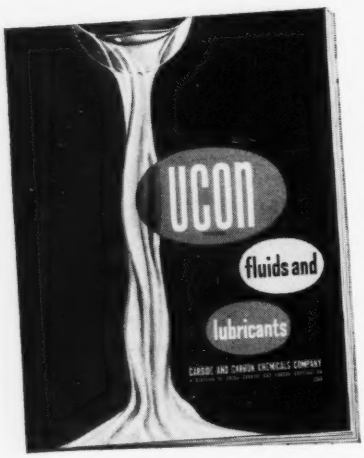

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On the Friction of Cast Iron Against Chromium-Plated Steel, by M. Kontorovich & V. Arkharov; "Vestnik Metallopromyshlennosti," Vol. 20, No. 10, 1940, pp. 10-12; 2 figs., 1750 words. Experimental apparatus and procedure for measuring coefficient of static friction of gray iron against hardened and unhardened steel before and after chromium plating the latter under three different sets of conditions (dull, bright, and milky deposits). Effect of base material on friction coefficient of Cr plates. Best plating conditions for minimum coefficient of friction. (Order No. 1543, price $2.65)

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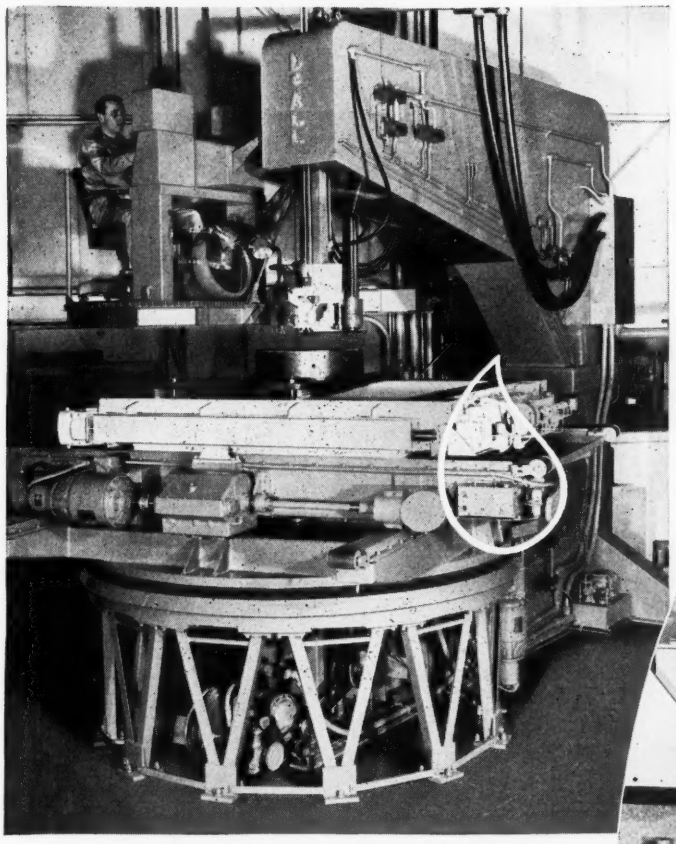
(Continued on p. 277)



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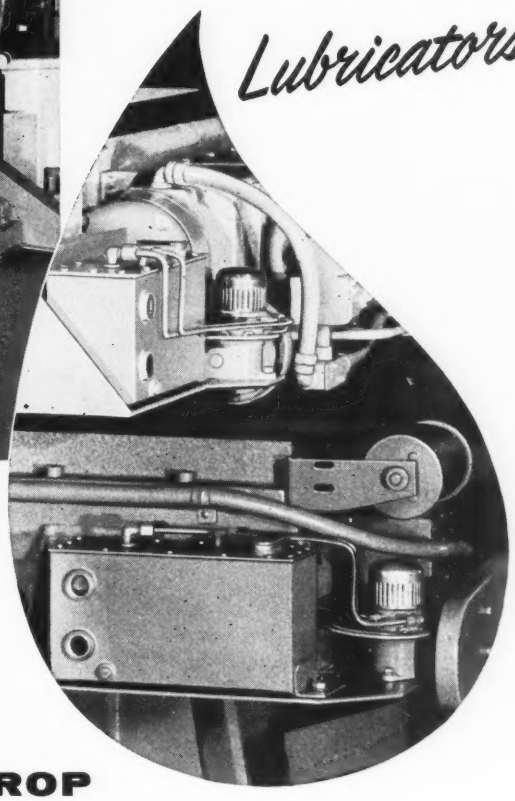

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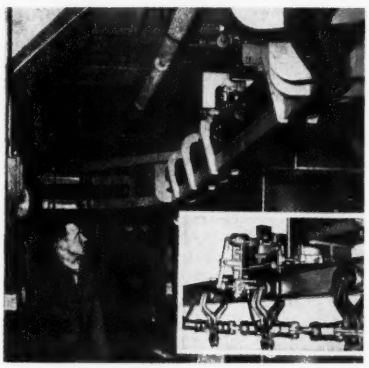
(Continued from p. 274)

fluence of surface-active substances upon process of sintering. Conclusions drawn from experimental results as to suitability of method of electrical conductivity. (Order No. 3065, price $6.40)

Effect of Specimen Dimensions upon Adsorption Fatigue & Corrosion Fatigue of Steel, by G. V. Karpenko & A. V. Karlashov; "Doklady Akademii Nauk SSSR," Vol. 92, No. 3, 1953, pp. 603-605; 2 figs., 1 table, 1500 words. Experimental study of influence of absolute dimensions (diameter) of steel specimens under cyclic stress upon their adsorption fatigue strength (in lubricating oil), corrosion fatigue strength (in water), and fatigue strength in air. Criteria adopted for expressing the effect of the surrounding medium upon the fatigue strength, and the effect of the specimen dimensions. Composition and tensile properties of steel used in study. Preparation of specimens and experimental procedure. Numerical data on fatigue limit of steel specimens in air, MS oil activated with oleic acid, and river water, as function of specimen diameter. Importance of part played by the condition of the specimen surface under cyclic loading for a rational evaluation of the authors' test results. (Order No. 3252, price $2.90)

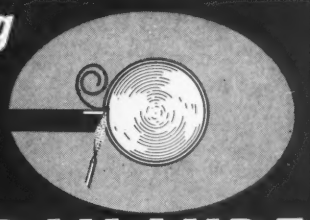
Cover Story —

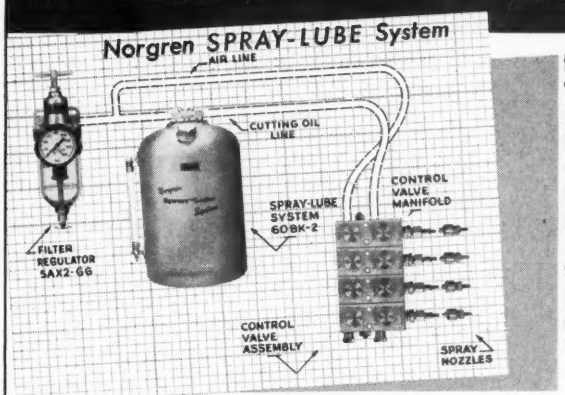


Lubricating Conveyor Trolley Wheels. Ask any lubrication engineer to name one of the most difficult of all lubrication jobs. If his plant is equipped with overhead conveyors using trolley wheels, chances are that this piece of equipment will receive his nomination. Since there are nearly 19,000 miles of overhead conveyor systems in operation in American industry today, it's an all-too-common problem.

Many larger plants have three or four miles of track right within their own four walls. How to lubricate these trolley wheels? There may be several thousand in the installation — each

Faster Metal Cutting at LOWER COST with improved Norgren SPRAY-LUBE





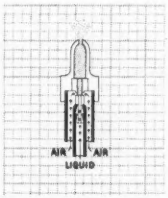
for
Tapping Machines
Drill Presses
Milling Machines
Grinders
Lathes
Boring Machines
High-Speed Saws
Stamping Presses
Die Lubrication
Other Metal Working Equipment

Better Lubrication—A better, more uniform spray of cutting oil is applied directly upon the close interface between the tool and work piece. It can be directed from the underside of the curled chip or from any other angle that will best reach the critical lubrication points. Tool wear is less—saves tool costs, cuts down-time.

Faster Cooling—Because of the larger fluid surface area of the spray and the expansion of the compressed air, heat is dissipated quicker. Cutting can be faster—production stepped up.

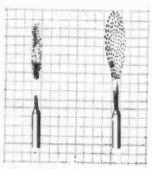
Uniform Spray

Air and cutting oil, with flow of each accurately controlled, are conveyed to the nozzle by means of a tube within a tube connection. The oil spray produced by the discharge nozzle is consistently uniform in quality. The spray is delivered to the cutting area the instant the machine is turned on. There is no sputtering or intermittent flow.



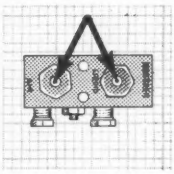
Accurate Control of Spray

By adjusting the pressure and the individual outlet controls for air and coolant, spray can be applied in exactly the right quality and quantity for any metal cutting or metal forming job.



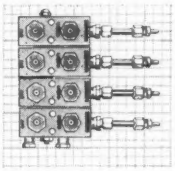
Tamper-Proof Controls

Allen-head screws are used on the control valves for adjusting flow of both air and liquid and are recessed into valve to prevent tampering with flow.



Valves Compactly Manifolded

For multi-point application of SPRAY-LUBE, the control valves are designed so that they can be closely assembled in a manifold arrangement.



Compact, Convenient Size

A space only 14"x20"x7" is required for a 2-gallon unit—4 to 12 fluid ounces of liquid an hour per nozzle are sufficient for most operations.

C. A. Norgren Co.
3434 So. Elati St., Englewood, Colo

Without obligation, learn how improved Norgren SPRAY-LUBE can reduce costs in your plant. Call your nearby Norgren Representative listed in your telephone directory — or WRITE THE FACTORY FOR BULLETIN 537.

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in the preparation of:

Cutting Oils
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Metal Working Oils
Engine & Heating Fuels
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For
Exceptional Performance
at Low Cost
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- CRESOL 22-C, Engine and Heating Oil Additive to prevent carbon deposits

Samples, and suggested formulae for general or specific applications, available upon request.

★

BURNS LABORATORIES, INC.
514 WEST WYOMING STREET
INDIANAPOLIS, IND.

pair of wheels having lubrication fittings on opposite sides of the track. Doing the job by hand is tedious and highly expensive. Lubricating the wheels while the system is in operation is almost impossible with a hand gun. Lubricating the system off-shift when the system is shut down for the night still means plenty of trips up and down the step-ladder, with resulting safety hazards, since overhead track is almost always hard to reach.

In addition, manual lubrication of overhead trolleys presents the twin problems of over-lubrication and under-lubrication. Too much lubricant can mean product spoilage or drippage with fire hazard wherever the conveyor travels. Not enough lubricant means noisy operation as well as wear and tear. Since the work flow in many plants depends largely on the conveyor system, the cost of shutdown comes high.

Shown on the front cover of this issue is one of the specialized lubricators now available for automatic lubrication of conveyor trolley wheels. The lubricator delivers a pre-set constant shot of either oil or lubricant to each trolley wheel on each side of the conveyor system into which it is installed, simply by the flick of a switch. When every wheel in the system has been serviced, the system may be switched off and is in constant readiness to go into operation again at whatever lubrication interval is required by load and other conditions.

The entire unit is contained on a section of I-beam 37¾ or 40" in length which is fitted into the conveyor track at any convenient spot in its length, so long as the location is within reach of the house airline and a 115 V., 60-cycle electrical outlet. Head-room of 22" over the top of the I-beam is usually required. As each wheel reaches the spot on the track at which the lubricator is installed, a coupler clamps the lubricant fitting on its hub and delivers the required amount of lubricant or oil. The coupler instantly disengages and is ready for the next wheel. As the applicator and coupler engage the grease fitting on each wheel, a pressure of from 800 to 1,000 pounds is applied which forces the lubricant into the bearing. The amount of lubricant can be adjusted to 0.005 cu. in. — enough for 32,000 shots from the 5-pound grease or 2½-quart reservoir.

Wheel spacing is no problem — they can be yards apart, irregular in spacing or as close as 8" on centers; and it is as easily adaptable to wheels 3" in diameter as to wheels 4 or 6".

When grease is used, the house air is regulated to apply pressure to a follower plate in the reservoir to assure delivery of lubricant to piston plunger.

This lubricator is a "package unit" complete with a section of track, also including the lubricant reservoir, right- and left-hand lubricator assemblies with protective covers and anchor plates. As an accessory to the trolley wheel lubricator, a mist lubrication system can be installed to automatically lubricate chain linkage and knuckle joints of load pendant hooks. (Submitted by Alemite Div., Stewart-Warner Corp.)

Coming Events

AUGUST, 20-25, American Mathematical Society, and Mathematical Association of America (Summer Meeting), University of Washington, Seattle, Wash.

SEPTEMBER, 7-10, American Statistical Association (Annual Meeting on Physics & Engineering Sciences), Sheraton-Cadillac Hotel, Detroit, Mich.

9-12, American Institute of Chemical Engineers (Regional Meeting), William Penn Hotel, Pittsburgh, Pa.

10-12, American Society of Mechanical Engineers (Fall Meeting), Denver, Colo.

12-14, National Petroleum Association (Annual Meeting), Traymore Hotel, Atlantic City, N. J.

16-21, American Chemical Society (Semi-Annual Meeting), Atlantic City, N. J.

16-22, American Society for Testing Materials (2nd Pacific Coast National Meeting), Hotel Statler, Los Angeles, Calif.

17-21, Instrument Society of America (11th Annual Conference & Exhibit), New York Coliseum, New York, N. Y.

24 & 25, Steel Founders' Society of America (Fall Meeting), The Greenbrier Hotel, White Sulphur Springs, W. Va.

25-28, Association of Iron & Steel Engineers (Iron & Steel Exposition & Meeting), Public Auditorium, Cleveland, Ohio.

OCTOBER, 8-10, ASLE-ASME 3rd Annual Lubrication Conference, Chalfonte-Haddon Hall, Atlantic City, N. J.

8-12, National Metal Congress & Exposition, Cleveland, Ohio.

18 & 19, National Conference on Industrial Hydraulics (12th Annual Meeting), Hotel Sherman, Chicago, Ill.

NOVEMBER, 7-9, Steel Founders' Society of America (Technical & Operating Conference), Carter Hotel, Cleveland, Ohio.

27-30, National Chemical Exposition, Cleveland, Ohio.

ASLE-ASME
Lube Conference
Oct. 8-9-10

(Section News, from p. 229)

MOHAWK-HUDSON Section. At a meeting held in Schenectady, N. Y., on April 25, 1956, under the guidance of E. R. Booser (ASLE President), W. E. Campbell (ASLE Past-President), and H. A. Wilson (ASLE Boston Section Chrmn.), plans were discussed for the formation of a new ASLE Section. With approximately thirty interested people from the area in attendance, the name "Mohawk-Hudson Section" was approved, temporary officers were elected (see ASLE Directory), and a petition for a charter was signed and forwarded to the ASLE National Office. In conclusion, Mr. Booser presented a paper entitled "Trends in Grease Lubrication." (Submitted by H. J. Sneck, Publicity Chrmn.)

N. CALIFORNIA, May meeting. Election of Officers (see ASLE Directory), followed by guest speaker Dr. D. F. Wilcock, General Electric Co., who presented a paper entitled "The How & Why of Ball Bearing Lubrication."

June. Fourth Annual Dinner Dance, held at the Commissioned Officers' Mess, Alameda Naval Air Station. (Submitted by A. C. West, Vice-Chrmn.)

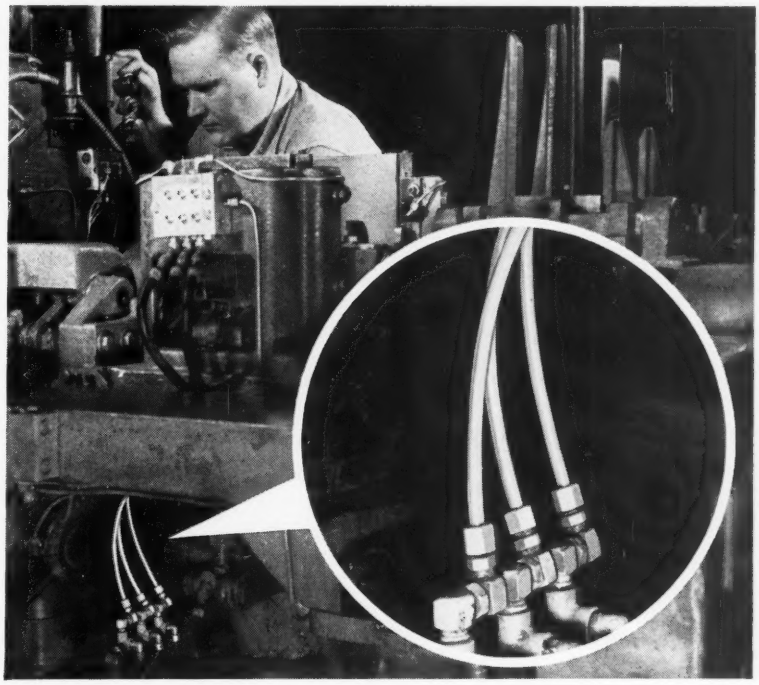
PHILADELPHIA, May meeting. Election of Officers (see ASLE Directory). (Submitted by F. L. Heist, Sec'y.)

(Lube in the News, from p. 227)

tions in atomic energy will be prominent among the subjects considered at the 12th annual National Conference on Industrial Hydraulics to be held in Hotel Sherman, Chicago, on October 18 & 19. The use of hydraulics in the nuclear energy field will be discussed at the opening general session, followed by ten technical sessions devoted to discussions of the latest developments in fundamental and applied phases of industrial hydraulics in other fields.

Chairman of the general session will be Dr. J. C. Boyce, Vice-President & Dean of the graduate division of Illinois Institute of Technology which, with its affili-

NYLAFLOW® Pressure Tubing cuts costs on machine tool lubrication systems



• High-speed production soon becomes "high-cost" production in the face of frequent downtime and expensive maintenance. Polymer's NYLAFLOW Pressure Tubing — specially processed from tough, horn-like nylon — helped solve this problem recently on a series of automatic machines:

PROBLEM:

Tubing connecting automatic lubricator to moving parts was required to withstand 400 flexes per minute under high internal pressure. Frequent failure due to pressure and flex fatigue of tubing caused excessive downtime, costly maintenance.

SOLUTION:

NYLAFLOW Pressure Tubing has been in continuous use for 12 months without a single replacement. This represents an increase in tubing life—*thus far*—25 to 1 over former tubing. NYLAFLOW required no special fittings, was less bulky and easily installed.

These characteristics show why tubing costs are low with NYLAFLOW:

- Flexibility—extremely long flex life.
- High Pressure Rating — higher strength / weight ratio than any other extruded non-metallic tubing.
- Easy Installation—light weight, easy to handle and cut, no pre-bending, uses standard fittings.
- Corrosion Resistant—impervious to most chemicals, hydrocarbons, solvents.
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Solve your tubing problems permanently with economical NYLAFLOW. Available in burst strengths of 1000 and 2500 psi. in various diameters. Write for performance data.

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Special Lubricants
MADISON, N.J.

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SPECIAL COMPOUNDED GEAR

LUBRICANTS, EXTREME PRESSURE

Belex Gear Lubricants are highly refined mineral oils which have been compounded with special extreme pressure additives. They are homogenized to increase their polarity; thus increasing their lubricating and extreme pressure properties. This process increases the lubricating qualities by building a tenacious mono-molecular film on surfaces of metal.

Belex Gear Lubricants have excellent rust and oxidation stability. Belex SAE #250 Gear Lubricant has exceptionally good high temperature stability.

MOLYLUBE

ANTI-SEIZE

A highly concentrated non-melting molybdenum disulphide grease. The molybdenum disulphide employed in Molylube Anti-Seize has the phenomenal capacity to prevent galling and seizing at bearing pressures well over 100,000 pounds per square inch. It has excellent lubricating qualities at low temperatures and elevated temperatures up to 750° F.

SEND FOR FREE
SAMPLE TUBE.

APPLICATION

Trunion Bearing
Speed Reducers
Hammer Mills
Other similar heavy duty applications where longer gear and bearing life is desired.

BEL-RAY Company Inc.
MADISON, NEW JERSEY

ate, Armour Research Foundation, is sponsoring the Conference in cooperation with several engineering societies (including ASLE) and more than 100 industrial organizations. Conference Director is R. O. Isenbarger, Chief Engineer of Chicago Rawhide Mfg. Co.

The schedule of technical sessions, with subjects and names of chairmen, includes:

Oct. 18 (p.m.): "Pumps," J. A. Lauck (Borg-Warner Corp.); "Servo-Systems," R. J. King (Caterpillar Tractor Co.); "Components & Accessories," J. O. Heyworth (Barco Mfg. Co.); and "Pneumatics," J. J. Slomer (Goodman Mfg. Co.).

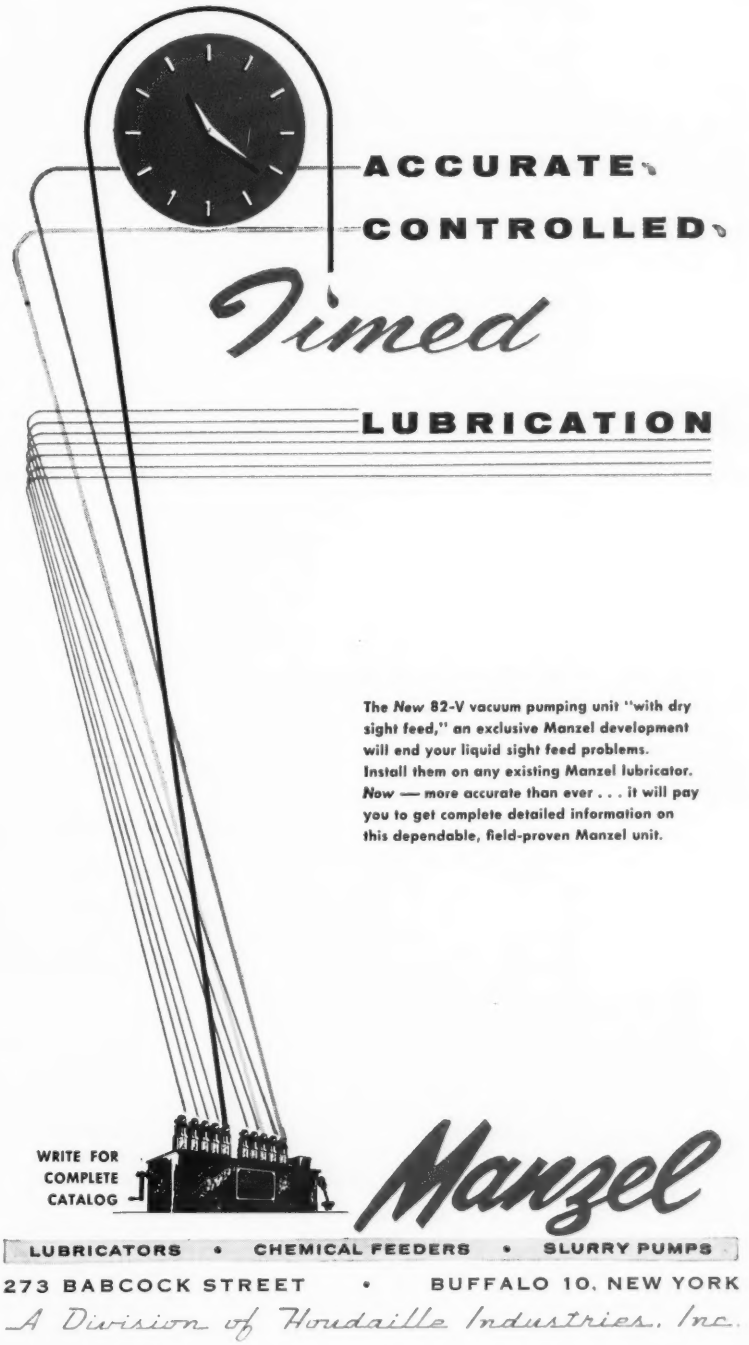
Oct. 19 (a.m.): "Mobile Equipment," J. F. Ziskal (International Harvester Co.); "Machine Tools," E. J. Svenson (John S. Barnes Corp.); and "Aircraft Systems," J. T. Marshall (Bendix Aviation Corp.).

Oct. 19 (p.m.): "Hydraulic Fluids," R. Q. Sharpe (Socony Mobil Oil Co.); "Presses," M. G. Sulser (Denison Engrg. Co.); and "Automotive," F. L. Mackin (General Motors Inst.).

(New Products, from p. 233)

all types of petroleum laboratories where vapor pressures of gasoline are run daily. The unit consists of a stainless steel bath approximately 19″ dia. by 30″ high, and is equipped with a single track for holding 3 bombs or a double rack for holding 5 bombs. Temperature is maintained at 100° F., within A.S.T.M. limits, utilizing a combination of a fully-enclosed armored preset sealed mercury regulator, with electronic relay and motor-driven stirrer. The motor-driven stirrer utilizes an explosion-proof motor, and the electronic relay, pilot light, switch, and line switch are mounted in an explosion-proof housing. All explosion-proof fittings, etc., conform to meet the requirements of Class 1, Group C and Group D. (Bulletin 4013EX, Labline, Inc., LE-12/4, 3070 W. Grand Ave., Chicago 22, Ill.)

Flushing Drop Feed Oilers. Upon starting a bearing, it is sometimes


ACCURATE
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LUBRICATION
The New 82-V vacuum pumping unit "with dry sight feed," an exclusive Manzel development will end your liquid sight feed problems. Install them on any existing Manzel lubricator. Now — more accurate than ever . . . it will pay you to get complete detailed information on this dependable, field-proven Manzel unit.
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desirable to supply a substantially-increased amount of oil for a short time to insure proper lubrication. Recently-developed Drop and Flush Oilers provide a simple means to automatically flood or flush a bearing with a definite amount of oil at the starting period after which oil will feed drop by drop. The quantity of oil provided for flushing is fixed, while drop feeding can be adjusted. After the oiler is shut off, it automatically resets itself for the next operating period. Oil is released by gravity from a reservoir. The drop feeding can be observed and adjusted within a wide range on the sight feed valve, and any setting retained by means of a friction screw. Extra-fine metering valves are optional and feed at an extremely slow rate. Two styles are available: Style DEY, which is solenoid-operated; and Style DOY, a manual unit. (Oil-Rite Corp., LE-12/4, 2328 Waldo Blvd., Manitowoc, Wis.)

High-Pressure Oiler. The first hand-operated high-pressure oil gun for contacting standard lubrication fittings has been announced, making it possible to have positive pressure lubrication with oils as well as flushing and cleansing of bearings which require periodic applications of fluid lubricant. Used with the pressure oil gun are metal rings anodized in various colors. They are slipped over the head of each fitting to provide a color coding system for all bearings requiring oil. In addition to simplifying standardization, these rings make the accidental use of a grease gun impossible. (Lincoln Engineering Co., LE-12/4, 5743 Natural Bridge Ave., St. Louis 20, Mo.)

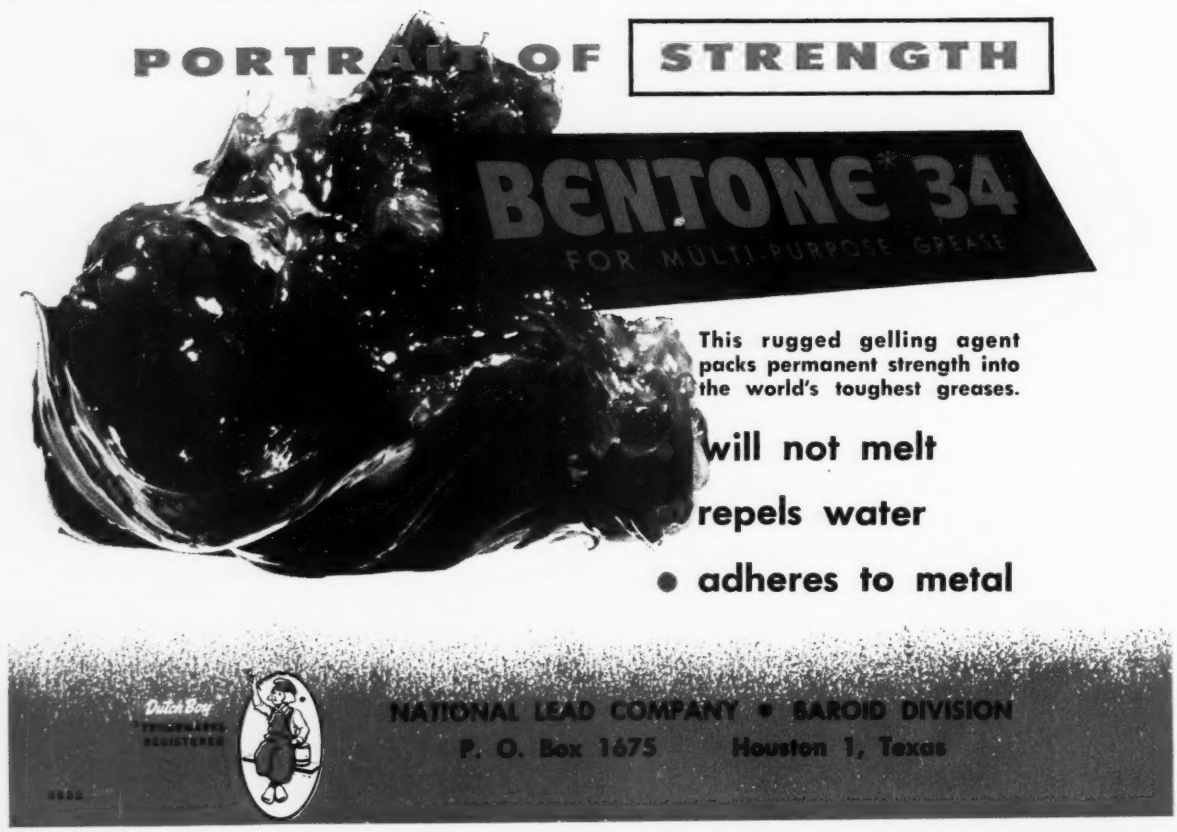
Patent Abstracts

(Compiled by Ann Burchick, Aluminum Co. of America.)

Poly-Oxyalkylene Glycol Lubricant Compositions, Patent No. 2,721,177 (O. L. Harle, assignor to California Research Corp.) A lubricant composition comprising a major portion of an aliphatic, monohydric alcohol-initiated poly-1,2-oxyalkylene glycol of lubricating viscosity in which the alkylene groups are selected from the class consisting of ethylene and 1,2 propylene groups, together with from about 0.1 to 5% by weight of a primary inhibitor selected from the class consisting of phenyl-2-naphthylamine and tert.-butylcatechol and an amount, sufficient to provide the lubricant composition with from about 0.25 to 2% by weight sulfur.

Extreme Pressure Lubricant, Patent No. 2,720,491 (Helen S. Beretvas, assignor to Standard Oil Co.) A normally liquid extreme pressure lubricant comprising a mineral lubricating oil and a minor amount of a complex double soap having the general formula RCOOPbOOCR' wherein R represents a naphthenic acid radical and R' represents the acyclic radical of a carboxylic acid containing from 2 to about 6 carbon atoms which carboxylic acid is selected from the group consisting of unsaturated carboxylic acids and hydroxy carboxylic acids.

Poly-Oxyalkylene Glycol Lubricant Compositions, Patent No. 2,721,178 (O. L. Harle, assignor to California Research Corp.) A lubricant composition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BENTONE 34
FOR MULTI-PURPOSE GREASE
This rugged gelling agent packs permanent strength into the world's toughest greases.
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Furthermore this fast, reliable oil check has revealed many potential troubles in advance, such as oil contamination due to block fracture... in time to save costly repair bills. The Cleveland-Lorain Highway Coach Co. is enthusiastic about it.

The Shell ADC Oilprint Analysis enables fleet operators to test crankcase oil in the short time allotted for re-fueling and crankcase oil checks . . . mere *minutes*. It eliminates draining still-good oil and the risk of using oils loaded with contaminants.

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The operator places just one drop of oil on the card. Analysis gives conclusive check of oil's condition.

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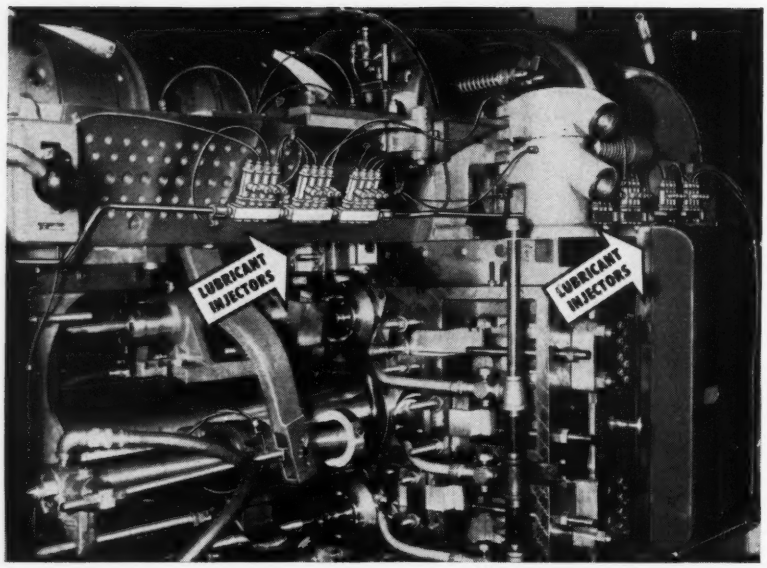

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Lincoln "mechanized maintenance" at work: Heavy Duty Way Oil is supplied to lubricant injectors, serving 78 bearings, simultaneously each time System is cycled.

Lincoln's new Centralized Power Lubrication Systems automatically apply refinery-pure lubricant in measured quantities to all bearings —while equipment is in operation! Here's the modern way to save man-hours, eliminate lubrication down-time and needless repairs. Surprisingly low in cost, these Lincoln Systems are lengthening service life of equipment and increasing productivity and profits . . . in widely diversified industrial and automotive applications!

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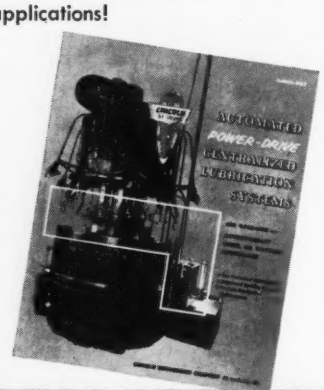
tells how to "build in" automatic maintenance for top performance . . . gives information and specifications on Lincoln Power Lubrication Systems for automated lines . . . machine tools . . . production equipment . . . materials handling equipment. Write for your copy today!



Lincoln

LINCOLN ENGINEERING COMPANY

Division of McNeil Machine & Engineering Co.

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comprising a major portion of an aliphatic monohydric alcohol-initiated poly-1,2-oxyalkylene glycol of lubricating viscosity in which the alkylene groups are selected from the class consisting of ethylene and 1,2-prophylene groups, together with from about 0.1 to 5% by weight of a primary inhibitor selected from the group consisting of phenyl-2-naphthylamine and tert.-butylcatechol and an amount sufficient to provide the lubricant composition with from about 0.25 to 2% by weight sulfur of a sulfur-containing polyoxyalkylene glycol having a molecular weight between about 180 and 3000.

Aldehydes as Polymerization Modifiers in the Production of Liquid Polymers, Patent No. 2,721,879 (A. H. Popkin & J. M. Phelan, assignors to Esso Research & Engineering Co.) In a process for the preparation of lubricating oil additive materials which comprises copolymerizing (1) a substantially neutral ester of (a) substantially saturated primary aliphatic alcohol containing in the range of 1 to 18 carbon atoms and averaging about 7.5 or more carbon atoms per molecule and of (b) a material of the class consisting of alpha, beta-unsaturated polycarboxylic acids and their anhydrides with a low molecular weight vinyl ester in the presence of a peroxide catalyst, the improvement which comprises the use of about 0.1 to 10% by weight of an aliphatic aldehyde.

Grease Compositions Containing An Antirust, Patent No. 2,722,516 (R. L. Merker). An improved lubricant grease comprising a base lubricating fluid thickened with a metal soap and containing a small, rust-inhibiting proportion of a water soluble neutral salt of an alkylene dicarboxylic acid of 8 to 10 carbon atoms in which the carboxylic acid groups are linked to the opposite terminals of an alkylene chain of from 6 to 8 carbon atoms.

Lubricating Oil Modifiers, Patent No. 2,722,517 (P. V. Smith, Jr., Frederick Knoth, Jr. & W. E. Waddey, assignors to Esso Research & Development Co.) A lubricating composition comprising a major proportion of a mineral lubricating oil, 0.5-2% by weight, based on the total composition, of the product obtained by contacting about 1 mol of PCl_5 with about 3 mols of ethylene oxide while stirring and cooling approximately to room temperature, and 5-15% by weight, based on the total composition, of sulfurized sperm oil.

Synthetic Lubricants, Patent No. 2,722,518 (F. J. Watson, assignor to Shell Development Co.) A lubricating composition comprising a major amount of an aliphatic ester of a phosphorus acid having dispersed therethrough from about 0.25% to about 5% by weight each of a thiodiphenylamine and a diaminodiphenyl alkane, said alkane containing from 1 to 2 carbon atoms.

3rd

ASLE-ASME

Lubrication Conference

Chalfonte-Haddon Hall

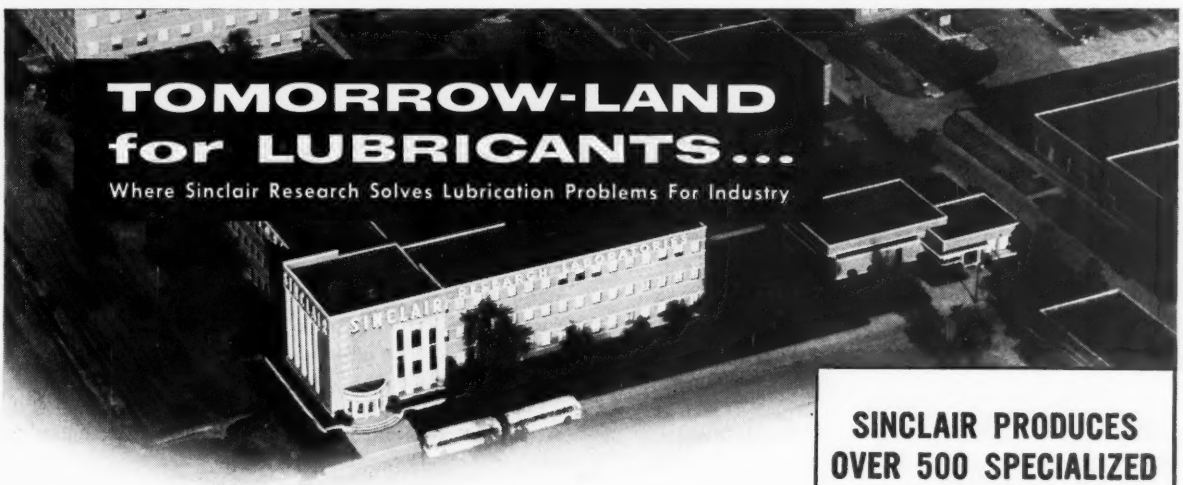
October 8-9-10, 1956 **Atlantic City, New Jersey**

(Lube Lines, continued from p. 231)

lubricating system to promote emulsions and other oxidation-susceptible residual matter. One of the most active programs in petroleum research today is the study of anti-oxidant additives. Remarkable resistance of lubricating oils and greases is obtained by inclusion of certain of these additives.

Since the oxidation process requires oxygen, it is obvious that air — the primary source of oxygen — must be present. As a matter of fact it always is present because machinery is not customarily run even under partial vacuum conditions. Air, in turn, contains more or less moisture according to the humidity, and, as indicated, moisture acts to promote the objectionable results of oxidation — emulsion-sludge. An example of the non-lubricating nature of such materials is found in the oil filter on the average automobile. With a by-pass type of filter only a small percentage of the crankcase oil is passing through the filter while the engine is running. The amount of sludge which can be accumulated in the filter element over just a few thousand miles of operation is an indication of the extent to which chemical decomposition of the oil has occurred, coupled with contamination by dust and dirt which has gained entry through the crankcase breather. Failure of crankcase oil to effectually protect such an engine is forestalled by adherence to the procedure of periodic oil changing and renewal of the filter element. An expenditure of not much more than five dollars every two to three thousand miles of operation is good insurance for an engine which is worth several hundred dollars.

The cost of lubrication should not be regarded merely as the cost of lubricants. In fact, the latter is just one of the items which contribute to effective lubrication. Coupled with the cost of lubricants is the cost of the lubrication procedure, the equipment required for storage, handling, and application; the item of proper supervision, and the relation to maintenance. Actual cost of the lubricants in most types of service is virtually negligible as compared with the insurance value of an effective lubrication program. It applies equally as well to the family automobile as to a million dollar steel rolling mill installation.



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"Sticky" conveyor problem solved by colloidal graphite lubrication

For a number of years, Whitehall Pharmacal Company, nationally known pharmaceutical manufacturer in Elkhart, Indiana, had lubrication problems with the bucket conveyor to its coal-storage elevator. Pin wear was excessive, due to abrasive coal dust and the corrosive effects of moisture . . . until they tried lubrication with a **'dag'** dispersion of colloidal graphite in mineral spirits.

Diluted 1:7 with mineral spirits, **'dag'** dispersion No. 2404 is now sprayed on the conveyor links, as shown in the photograph, at two-week intervals. The compressed-air jet carrying the dispersion blows away accumulated dirt . . . lets the volatile carrier deposit a microscopic film of graphite around the pin and link. The resulting *dry lubricating film* is exceptionally durable, provides effective lubricating action, and inhibits corrosion. Whitehall reports that maintenance expense for the conveyor has been drastically cut and down-time all but eliminated.

'dag' dispersions are ideal for conveyor lubrication since they resist abrasion, provide lubrication under extreme pressures, and are not affected by high temperatures. They are suitable for application by automatic oilers and mist lubricators.

Write for more information, contained in Acheson Bulletin 423.

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C-5039 Res. Chem. Chem. age to 36, 3+ yrs. in analytical chem. using instrumental analysis; know both organic & inorganic analytical work; duties: non-routine analytical work on alum. alloys, complex alloys, rolling oils & lubr. corrosion prod. plating baths, alum. paints & finishes & furnace skim; for a mfr. of alum. sal. up to $735/mo. loc. Wash.

C-5049 Asst. Dist. Supt. Chem. E. Age to 40; 3+ yrs. in operating chem. plants; duties: asst. dist. supt. in supv. the oper. of sev. chem. plants mfg. carbon dioxide gas; co. will pay moving exp. for a mfr. of gas; sal. $7-8000/yr. + profit sharing; loc. N. J. empl. will pay the fee.

C-5050 Dist. Supt. Chem.E. or ME; 5+ yrs. in operating chem. plants; duties: in chge. of several plants mfg. carbon dioxide gas; co. will pay moving exp. for a mfr. of gas; sal. $9-9500 + profit sharing; loc. 1-East Coast; 1-Midwest empl. will pay the fee.

C-5061 Chem. Engr. Chem. or Chem. Eng. age up to 30; 2+ yrs. in pharmaceutical lab. work; duties: combined dev. & prod. work in pharmaceuticals; for a mfr. of pharmaceutics; sal. $100-115/wk. loc. Ill. empl. might negotiate the fee.

C-5066 Rubber Chem. PhD. Chem. age to 35; 3+ yrs. in fundamental res. in organic chem; knowl. of rubbers helpful; duties: import res. work in the field of rubber chems. for a mfr. of rubber; sal. $650-850/mo. loc. Ohio, empl. will pay the fee.

C-5067 Refinery Supt. Chem. Eng. 6+ yrs. in res. processing; know atmospheric distillation units, UOP cat. crackers & sim. eqpt. duties: dir. the activities of the various depts. & units of the refinery in order to get the job done most effectively & efficiently; for a refiner of pet. sal. $850-1000/mo. + moving exp. loc. Okla. empl. will pay the fee.

C-5068 Jr. Engrs. Pet. ME CE or Physics; 2+ yrs. in drilling or prod. oper. in petrol. ind.; duties: training for drilling, refining or prod. work in the petrol. ind. for a refiner of pet.; sal. $475-550/mo. + moving exp. loc. Okla. empl. will pay the fee.

C-5070 Process Engr. Grad. Chem. 3+ yrs. in pet. refin; duties: resp. for formulating program for investigation of new & improved refinery tech. performing process & economic calcs. for a refiner of pet. sal. $650-750/mo. + moving exp. loc. Okla. empl. will pay the fee.

C-5071 Asst. Gen'l Supt. Pet. Chem.E. age 30-40, 5+ yrs. in gasoline plant processing, constr. or operation; know operation & des. of gas. plants; duties: asst. gen. supt. on operations, personnel prob. in gas testing, new plant loc. budgets, safety, estimates & other phases of gen. oper. for a refiner of pet. sal. $7-750/mo. + moving exp. loc. Okla. empl. will pay the fee.

C-5122 Materials engr. Rubbers & Plastics Chem. or Chem.E, 4+ yrs. in lab. or dev. in rubber or synthetics; know des. of small parts & qual. control; duties: supv. mat'ls. control lab. on rubber, synthetics & plastics for a mfr. of valves; sal. $6-700/mo. loc. Chgo. empl. will pay the fee.

C-5126 Sales Chem. or Chem.E. age 25-35; 1+ yrs. in sales of chems. duties: selling ind. a line of chems. 70% trav. home week ends, car furn. for a mfr. of borax; sal. $450-500/mo. + exp. loc. Chgo. Hdq.

C-5129 Sales Chem. or ME; 1+ yrs. in sales or allied work; knowl. of water treating helpful; duties: sales, est. & possibly internal sales work from a mfr. of water treating; sal. $5-9000/yr. loc. N.Y., empl. will pay the fee.

C-5169 Asst. Chief Project Engr. Chem. or ME; age up to 45; 5+ yrs. in lge. scale project supv. in des. of process plants or eqpt. duties: supv. process plant project work incl. plant & eqpt. may also have some field or operating assignments for a mfr. & engr. of process plants; sal. up to $12,000/yr. loc. Pa. empl. will negotiate the fee.

C-5170 Project Engrs. ChemE. or ME age up to 40; 1+ yrs. in process engr. ind. on des. of plants and/or eqpt. know unit operation in process field; duties: project work on des. & selection of process eqpt; des. of entire plants & maybe some field work for a mfr. & engr. of process plants; sal. up to $12,000/yr. dep. on exp. loc. Pa. empl. will negotiate the fee.

C-5173 Gas Operating Supt. 3+ yrs. supv. gas plant operation; duties: in charge of multi-unit oxygen plant of about 24 empl. operating 3 shifts; must be acquainted with labor relat. work for a mfr. & eng. of process plants; sal. up to $7200/yr. loc. several, empl. will negotiate the fee.

C-5175 Chem. Process Engr. Chem.E. age up to 35; 1+ yrs. in processing the physical separation of complex, low molecular weight mixture; duties: process engr. work in chem; petrochem. or petroleum refining plants & operations for a mfr. & engr. of process plants; sal. up to $8000/yr. dep. on exp. loc. Pa., empl. will negotiate the fee.

C-5176 Dev. Engr. Chem.E. or ME; age up to 50; 2+ yrs. in dev. problems of heat transfer, cas to liquid contact; duties: dev. work analyzing projects, calc. experimental test facilities eqpt. of chem. unit operations for a mfr. & engr. of process plants; sal. up to $12,000/yr. dep. on exp. loc. Pa. empl. will negotiate the fee.

C-5185 Chief Chem. Chem. age up to 40; 5+ yrs. in supv. work in minerals ind. know analytical inorganic chem; duties: construct, estab. & supv. an analytical lab. for making complete analysis of bauxite samples in the field; will have complete chge. of oper; for a mfr. of alum. & chems. sal. $775-1,050/mo. + exp. loc. Brazil.

C-5213 Chief Chem. College; age 25-45; exp. in pet. (oils & greases) formulation, qual. control; know lubricants; duties: qual. control test work, formulation, res. & dev. in lab; making infrequent trips with field sales engrs. who have complaints on products or who require explanation of new product application; for a mfr. of lub. oil & greases; sal. $6-800/mo. loc. Ohio, empl. will negotiate the fee.

C-5225 Editor. Elect. training; age up to 40; 1+ yr. in utility work; duties: gen. editorial work ⅓ trav. for a publisher of a trade mag. sal. $6-8000/yr. loc. Chgo. or N.Y. empl. will negotiate the fee.

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Studies in Centralized Lubrication
No. 193

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Above—four pan feeders and their screens at the Sherman Crushing Plant. Below—close-up of Farval valves serving a feeder.

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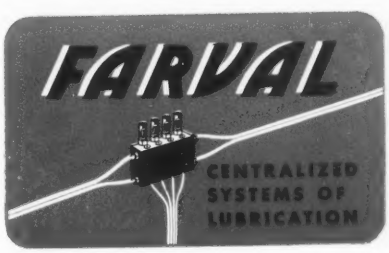

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